IS POLIO BACK? p.7

SPEED IN SPACE
Ultimate Rockets p.70

HUMAN ORIGINS
The Birth of Creativity p.66

SCIENCE FOR THE CURIOUS

Discover®

June 2015

Mysteries in Time

Is the past a myth?
Is the future set?
Is it all an illusion? p.38

PLUS

Death in the Lab p.52

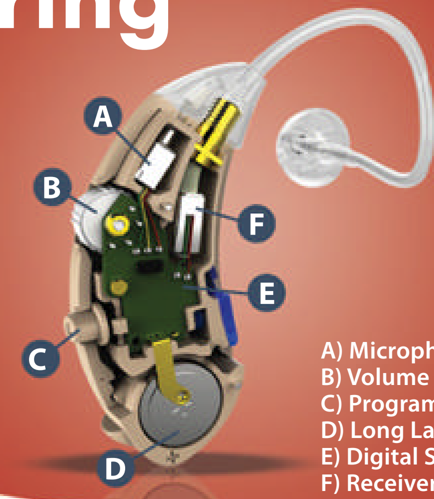
Museums Under the Sea p.46

What the First Microscopes Saw p.58

BONUS ONLINE CONTENT CODE p.5

Affordable Hearing Aid Technology Only $299!

Learn about our great digital technology at an affordable price.



FREE 1 YEAR Supply Of Batteries*

A) Microphone
B) Volume Control Wheel
C) Program Button
D) Long Lasting Battery
E) Digital Signal Processor
F) Receiver (Speaker)

The All New HCX!

- Digital sound processing chip provides **crystal clear sound and makes speech easier to understand** without feedback
- Multiple memory programs **adapt to most listening situations**
- Nearly invisible thin tube design
- Helpful **low battery warning** so you are never caught unprepared
- **Long lasting size 13 batteries**
- 10 bands of layered noise reduction helps to **emphasize voices while balancing out background noise**
- **100% Money Back Guarantee**

The HCX™

★ Customer Reviews ★

"I will definitely recommend your company to my patients."

- Dr. Arun P.

"I just want to let you know how happy my husband and myself are with his new hearing aids! We had no idea it would be such a fast, simple and enjoyable process..."

- Monique S.

Digital Hearing Aid Technology... For Only $299!

All hearing aids work the same way. The **microphone** picks up the sound and sends an electrical signal to the digital signal processor. The **digital signal processor** is the "brains" of the hearing aid. It takes the sound it receives and adjusts the sound to amplify important speech sounds as well as filtering out unwanted noise. To ensure the best in quality, the digital processor is designed and manufactured right here in the **United States.** Once the processor has amplified the sound it is passed to the **receiver** (also known as the speaker) where it emits a corrected and amplified sound through the **sound tube** into your ear.

More importantly, our hearing aid works at a **fraction of the cost** of name-brand hearing aids. The HCX uses long-lasting **size 13 batteries**. In addition to the technical components of the hearing aid, we also include a **self-adjustable volume control** that can be modified with a light touch of the finger. You also receive a hearing aid with **3 different audio programs** that are designed to fit most desired sound profiles. These too are self-adjustable, requiring a light tap of the program button.

You can spend thousands for a high-end hearing aid or you can spend $299 for a hearing aid that just plain works. We are so sure you will love our product, that we offer a **100% Money Back Guarantee - Risk Free** if you are not satisfied for any reason. It's time to get great digital technology at an affordable price!

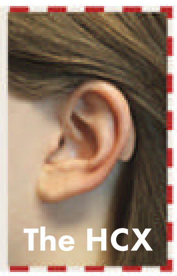
BUY A PAIR AND SAVE $50!

1-877-244-3320

Free 1 Year Supply Of Batteries!

*Use Coupon Code When You Order: **D56**

Visit Us: www.AdvancedHearing.com/D56



Advanced Affordable Hearing
Affordable Quality Since 1996!

Find us on Facebook

MONEY BACK 100% GUARANTEE

RISK • FREE • Trial

US Company Owned And Operated

FDA REGISTERED

Contents

JUNE 2015
VOL. 36, NO. 5

Researcher Matthew Maus attaches live elkhorn coral to dead coral to revitalize the Captain Kidd Living Museum of the Sea, off the shores of the Dominican Republic.

COURTNEY MICHALIK

ON THE COVER *Design by Dan Bishop/Discover; photo by Mipan/iStock*

Website access code: DSD1506
Enter this code at: www.DiscoverMagazine.com/code
to gain access to exclusive subscriber content.

FEATURES

COLUMNS & DEPARTMENTS

BOEING

p. 68

Editor's Note

View of the Future

Einstein says time is an illusion. This conscientious cosmologist has a different view.

I've always found stories about time, and human perception of it, endlessly fascinating, but also somewhat unnerving. Einstein held that time is just another dimension of the universe and that its passage is an illusion, that past, present and future coexist simultaneously.

Which I suppose would mean that Einstein didn't really come up with this idea 110 years ago — he's coming up with it at the same time that I'm writing about it, and at the same time that George Ellis, a conscientious cosmologist, is disputing that selfsame view of the universe. Specifically, Ellis holds that the future is not set and that it's dangerous to suppose that it is. He explains why in our cover story, "Tomorrow Never Was," beginning on page 38.

Speaking of time, a few issues ago I asked you where you would go if you could visit the past. Today it seems fitting to go in the other direction. If the future is set (as Einstein held) and you were somehow able to see it or visit it, how far ahead would you like to go? What scientific advances would you hope to witness? Email me at editorial@discovermagazine.com and share your view with me.

NEXT ISSUE: *Cleaner, greener ways to power the planet, the launch of our science history column and much more in our annual Invisible Planet issue.*

Stephen C. George, EDITOR IN CHIEF

YOUR REPLY

Boy, I really did get a lot of responses to my question from the March issue about which period of history you'd visit if you could. John Carter's answer was by far the most ambitious:

I would like to see a time-lapse, bird's-eye view of Earth from birth to now. Watching a thousand years fly by every second might seem really weird. Even more weird might be watching how life springs up and spreads across the face of the Earth — like watching a time-lapse view of bacteria spreading across a fallen leaf.

CONNECT WITH US

facebook.com/DiscoverMag
twitter.com/DiscoverMag
plus.google.com/+discovermagazine

WILLIAM ZUBACK/DISCOVER

THE CRUX

The Latest Science News & Notes

The Second Coming of Polio?

After an outbreak reminiscent of the early 1950s, neurologists worry about what's coming this summer.

A child receives the polio vaccine at a school in New York in 1954. In the summer of 2014, an outbreak of polio-like paralysis affected over 100 children in 34 states in the U.S.

BETTMANN/CORBIS

Jayden Broadway of Denver was one of dozens of children treated last fall for a polio-like illness. Many have not fully recovered.

CYRUS MCCRIMMON/DENVER POST/GETTY IMAGES

An outbreak in late 2014 of polio-like paralysis in children, unlike any experienced in North America in more than half a century, has physicians on edge about what this summer and fall may bring.

"Neurologists have been really unnerved by what we've seen," says Keith Van Haren, a physician at Lucile Packard Children's Hospital who has been treating cases in California. "We're all really hoping it disappears, but the most likely outcome is that this will come back."

Looking all but identical to classic poliomyelitis but caused by something other than the poliovirus, the illness — formally named acute flaccid myelitis — usually strikes a week or two after a patient recovers from an apparently ordinary respiratory infection. Patients suddenly cannot move one or more limbs. Occasionally they lose the ability to breathe. An MRI reveals the same hallmark feature as classic polio: inflammation and death of nerve cells in the spinal cord.

Between August and December, the illness affected more than 100 children in 34 states, at an average age of 8, according to the U.S. Centers for Disease Control and Prevention. At least 13 more cases were reported in Canada during the same period.

Even those numbers, generated only by reports from physicians who thought to contact the CDC, are likely an undercount.

"In California, a quarter of our cases have been adults," says Carol Glaser, a former medical officer with a branch of the California Department of Public Health. "I'm really concerned that people think this can only happen in kids."

Two-thirds of the children counted by the CDC have shown some improvement, but only two have fully recovered, and one-third showed no improvement whatsoever. Some of those children remain on ventilators.

Reports from doctors treating the illness began trickling into Glaser's office as early as June 2012. California eventually counted nearly 50 cases there over the next two years. "I remember vividly one neurologist saying to me, 'I've never seen this here before. I trained in India. I saw polio in India. This looks like polio,' " Glaser says. "There are clearly very strong similarities."

Since the poliovirus doesn't cause the disease, the polio vaccine won't prevent it. Researchers suspect that another virus, enterovirus D68 (EV-D68), is the culprit because a widespread outbreak of upper respiratory illnesses associated with

EV-D68 hit North America around the same time as this new polio-like illness. Sophisticated genetic research has also identified EV-D68 in many, but not all, of affected children's respiratory secretions.

The illness is presumably spread, like the cold virus, through coughing and physical contact. Doctors do not yet know how easily it is transmitted or what proportion of infected people develop the polio-like symptoms — mysteries Glaser will be working to investigate in her new position at health care giant Kaiser Permanente.

No vaccine exists for EV-D68, and no research is underway to develop one, according to an official at the National Institute of Allergy and Infectious Diseases. That failure to begin vaccine research is cause for concern, says Avindra Nath, a neuroimmunologist at the National Institute of Neurologic Diseases and Stroke.

"I do think we should be prepared," Nath says. He acknowledges the uncertainties about whether EV-D68 is the cause of acute flaccid myelitis, and even whether it will come back in another outbreak later this year. Still, he says, "We should be thinking of vaccines. Even assuming we have zero cases in 2015 wouldn't mean we wasted the money. It could come back another year. Once the organism has shown its ugly head, you have to be prepared for it to come back."

But James J. Sejvar, the neuroepidemiologist at the CDC who has been tracking the outbreak and issuing alerts about it, says that beginning work now on a vaccine would be premature.

"We have this strong temporal association with the EV-D68, but at this point we don't have a smoking gun to confidently say there is cause and effect," says Sejvar. Proof would come from finding the virus in affected children's cerebrospinal fluid, something nobody has seen yet. "Unless you're certain what is causing the illness," he says, "it's difficult to take specific actions."

Looking almost identical to classic poliomyelitis but caused by something other than the poliovirus, the illness usually strikes a week or two after a patient recovers from an apparently ordinary respiratory infection.

Sejvar also takes issue with predictions that the outbreak will return this year during the late summer and fall (the same seasonal pattern long observed, but never fully explained, in both polio and EV-D68).

"It's premature to expect that," he says. "It's not unusual to have a large outbreak of an enterovirus and then you don't see it for several years." Even so, he adds, "We're certainly going to be vigilant and continue to monitor to see if something happens this year."

Glaser hopes to find cases that doctors have not yet reported to the states or to the CDC — and learn more about who is most at risk — by mining Kaiser Permanente's large patient database.

"We have a serious syndrome going on," she says. While acknowledging the danger of speculation when so much remains unknown, she offers a cautious estimate: "I don't think there will be thousands of cases, but I do suspect it will be more [than last year]. To expect less would be foolish." – DAN HURLEY

INBOX

History Tripping

In the March issue, Editor in Chief Steve George asked, "If you could visit any period of human history or development, which would you visit, and why?" As always, our readers supplied us with tons of interesting and varied answers. Here are just a few:

→ "I would like to go back to the Renaissance. I would like to interview Leonardo da Vinci and ask him some questions." — *Michael L.*

→ "I would love to journey back to the Mesozoic Era. Paleontology is a passion of mine, and I'd want to see prehistoric animals, especially pterosaurs and aquatic fauna-like plesiosaurs and ichthyosaurs." — *Wade C.*

→ "Being a New World archaeologist, I would like to travel back to the first migration to the New World. The Egyptians were good enough to leave us a written language; those fascinated by early humans are left with no such easy out." — *Kelly M.*

→ "If I could visit any time in history, it would be the Late Bronze Age, when global warming — among other things — brought about the collapse of sophisticated civilizations and ushered in a Dark Age. There are parallels to our own time that we might learn from. Or not." — *Sue H.*

→ "As a youngster of 10, I was immersed in books on archaeology and photos of the Nile river and the statuary and art carved into the sides of the land flanking the water. I was devastated to hear the Aswan Dam would flood these great works of sculpture. A few were salvaged, but the majority of the antiquities were lost to the generations. If I could do anything, I would go back in time to the period before the dam was built." — *Joyce W.*

→ "I would like to see how the pyramids of Egypt were really built, by whom, and the reason why." — *Joe S.*

No Needles Necessary

How an insect-turned-syringe helped save an endangered species.

The Iberian lynx, the world's most endangered wildcat species, once numbered fewer than 200 in the wild. Now, more than 300 roam the Iberian Peninsula on Spain's southernmost tip. And late last year, Portugal welcomed its first pair of lynxes that were reintroduced into the wild from captivity.

The species owes much of its revival to the Iberian Lynx Conservation Breeding Program, which has reintroduced more than 70 lynxes since 2010. But the program got a key assist from an unlikely source: the bloodsucking triatomine assassin bug.

Female lynxes new to pregnancy and motherhood often lose their first litter because of inexperience and stress. So scientists track all females in the program to identify and monitor pregnant lynxes. The problem: They needed blood samples, but tranquilizing the cats to collect blood with a syringe could induce stress and increase risk of abortion.

"We couldn't [safely] test for pregnancy *at all*," recalls Katarina Jewgenow, a reproduction biologist collaborating with the program. So Jewgenow's colleague at the Leibniz Institute for Zoo and Wildlife Research in Berlin, conservation biologist Christian Voigt, suggested using triatomine bugs.

The bugs prick animals with their hollow, needle-like mouthpart, or proboscis, which injects pain-blocking, anti-clotting chemicals. It's 30 times thinner than standard syringe needles. Plus, the bugs are bigger than mosquitoes, so they can draw more blood and are easier to handle — the perfect syringe substitute.

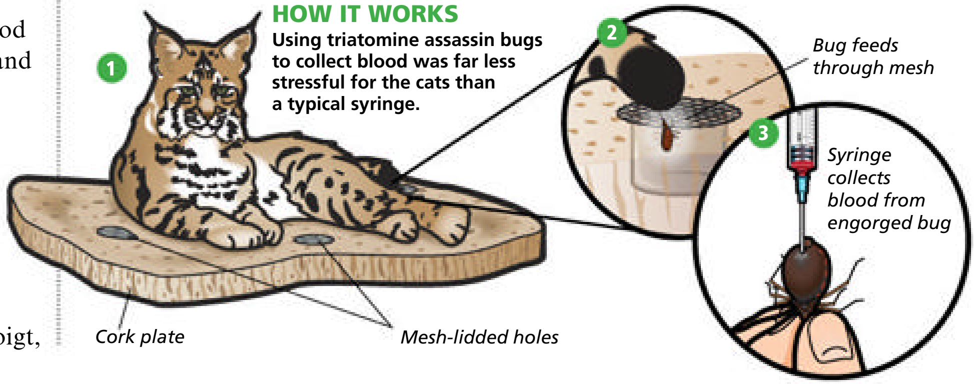
To test for pregnancy, biologists collected Iberian lynx blood via triatomine bugs (above). Successful conservation helped reintroduce this lynx (right) to the wild.

To collect lynx blood, Jewgenow placed the bugs into mesh-lidded holes in large cork plates that lined the lynxes' den floor. Whenever a lynx rested on a plate, the bugs feasted through the mesh. Jewgenow then collected the plates and extracted the blood from the insects' swollen abdomens.

This system worked for years until the team developed the fecal pregnancy test it uses today. Who would have thought these little bloodsuckers could help endangered wildcats return to their European homes? Not the lynxes; they never felt a thing. And that was the point. — YAO-HUA LAW

HOW IT WORKS

Using triatomine assassin bugs to collect blood was far less stressful for the cats than a typical syringe.



CLOCKWISE FROM TOP LEFT: DAVID MODRY; IBERIAN LYNX EX-SITU CONSERVATION PROGRAM/E. PEREZ; JAY SMITH

QUICK HIT

Batteries Safe Enough to Eat

The tiny batteries in your remote or key fob are convenient, but to a hungry (or curious) kid, they can pose a threat. The thousands of children a year who swallow them face throat burns, digestive tract damage and even death. Now a study in the *Proceedings of the National Academy of Sciences* details how scientists made working batteries that are virtually harmless inside our bodies.

Researchers coated batteries with a silicon-based material and metal particles, then fed them to pigs. The waterproof and pressure-sensitive coating didn't hurt the pigs, and the batteries remained functional in small electronic devices. Senior author Jeff Karp, a biomedical engineer at Brigham and Women's Hospital in Boston, hopes to see scalable prototypes this year. — ELIZABETH LANDAU

Pieces of Me

Scientists have long experimented with organs-on-chips: tiny representations of human organs, such as lungs, hearts and intestines, made from cells embedded on plastic about the size of a computer memory stick. Channels lined by living vascular cells then mimic the body's circulatory system. But our bodies are complex systems of organs, so testing drugs on individual miniature organs only goes so far. Researchers now are aiming for something more: full-blown human bodies-on-chips.

The kick-start came from the U.S. Department of Defense, which wanted a quick and effective way to develop and test drugs and vaccines against biological and chemical weapons. So federal agencies funded various projects to develop chips representing all the major organ systems. Each organ-on-a-chip hosts real human tissue kept alive by a synthetic circulatory system. Join enough of them together, and you've got a high-tech stand-in for the human body.

Researchers at Harvard's Wyss Institute have 12 different organ chips in development, representing everything from lungs to skin. They're working to combine 10 of them that will operate as a system for at least four weeks in an instrument called the Interrogator (named after its ability to analyze, or interrogate, how they work together). Don Ingber, the institute's director, says he and his colleagues already have succeeded in coupling two different pairs of chips — lung-liver and lung-heart — a key step toward the ultimate goal.

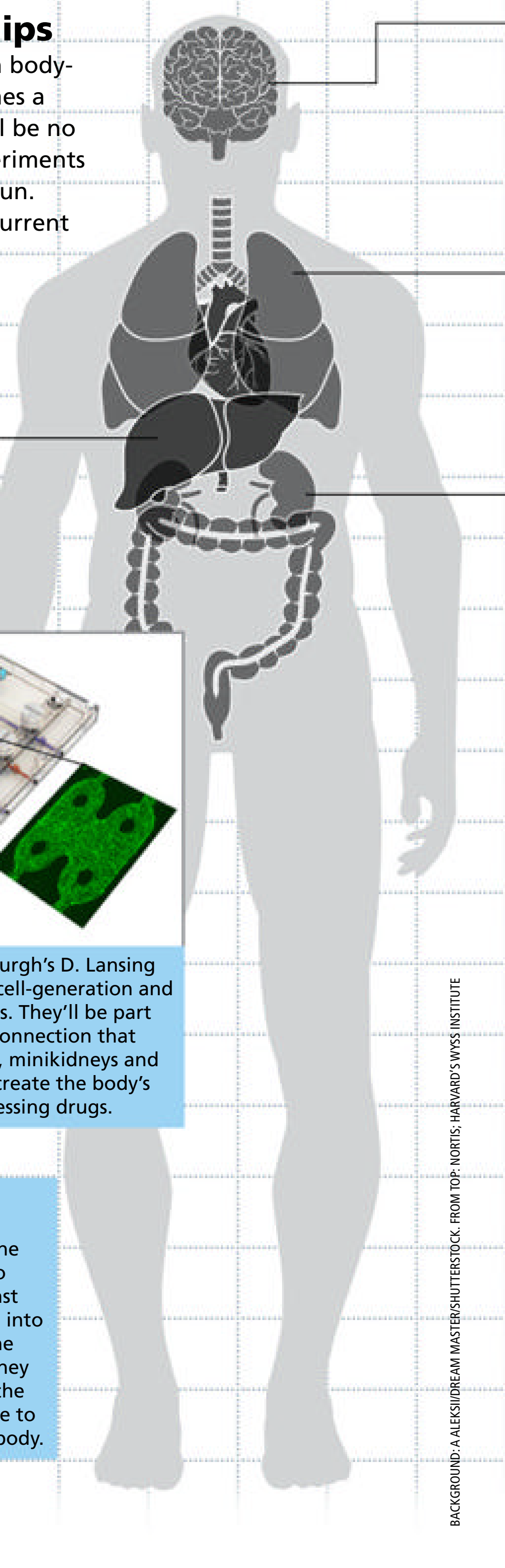
"These platforms are designed to be as close to human as you can get, but enable experimental manipulation," says D. Lansing Taylor, director of the University of Pittsburgh Drug Discovery Institute. Taylor is growing miniature livers that will be used to help re-create the body's main system for drug absorption and metabolism.

Human bodies-on-chips would have applications far beyond drug development. For instance, toxicologist Thomas Hartung of Johns Hopkins hopes that connecting his minibrains to other micro-organs will show how toxins affect neural development and how they're processed in the body. Conducting such brain experiments on animals is expensive and time consuming — and on people, it's impossible.

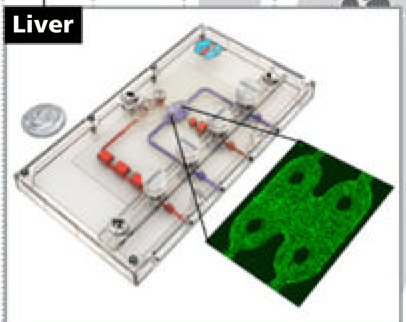
Enter the human bodies-on-chips. — ALEXANDER GELFAND

Human Chips

Once the human body-on-a-chip becomes a reality, there will be no limit to the experiments scientists could run. Here are a few current systems in place.



Liver



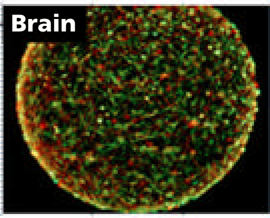
Minilivers from Pittsburgh's D. Lansing Taylor mimic a liver's cell-generation and detoxification abilities. They'll be part of a three-organoid connection that will link up minilivers, minikidneys and mini-intestines to re-create the body's main system for processing drugs.

The Interrogator

Harvard's Don Ingber wants to use the Interrogator to combine at least 10 organ chips into one system. The more organs they can combine, the closer they'll be to a real human body.

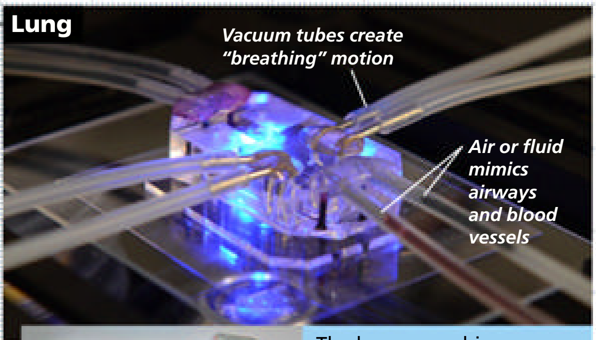
BACKGROUND: A ALEKSII/DREAM MASTER/SHUTTERSTOCK. FROM TOP: NORTIS; HARVARD'S WYSS INSTITUTE

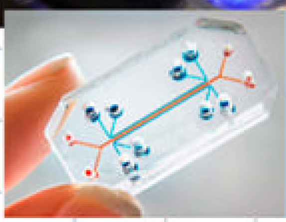
Brain



Thomas Hartung of Johns Hopkins is growing miniature brains that contain the same kinds of cells (left) found in full-size brains. Hartung hopes to build a brain-on-a-chip that can eventually plug into the Interrogator.

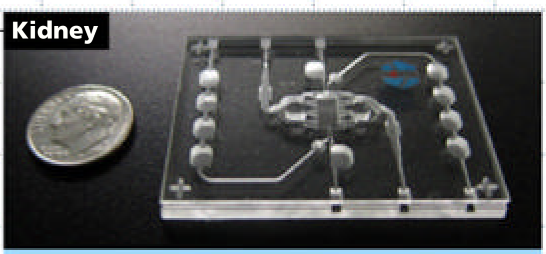
Lung





The lung-on-a-chip was the first human organ to be scaled down to chip form. Ingber's design, which should work with the Interrogator, re-creates the lung's processes with living cells.

Kidney



Taylor's minilivers also should combine with these miniature kidneys-on-chips, developed by scientists at the University of Washington.

Intestines

Fellow Johns Hopkins researcher Mark Donowitz, meanwhile, is working on the third part of the system, re-creating the functions of intestine cells (left). Researchers aim to combine every major organ system to create a true human body-on-a-chip stand-in.

Watch videos showing organs-on-a-chip at work at **DiscoverMagazine.com/Organs**

THIS PAGE FROM TOP: THOMAS HARTUNG AND DAVID PAMIES/JOHNS HOPKINS UNIVERSITY; HARVARD'S WYSS INSTITUTE (2); NORTIS; OLGA KOVBASNIUK. NUMBERS ILLUSTRATION BY ALISON MACKEY/DISCOVER. SMARTPHONE BY MATLINSKI/SHUTTERSTOCK

Random Acts of Transaction

An affordable and portable use of quantum-based tech may soon come to a smartphone near you.

The billions of credit card transactions each year in the United States rely on secure cryptographic keys based on random numbers, which require specialized hardware to generate. Now, European physicists have shown how smartphones like the one in your pocket can reliably produce random numbers based on the laws of quantum mechanics.

Modern smartphone cameras are sensitive enough to detect variations in light by just a few photons — the fundamental particles of light. Researchers at the University of Geneva exploited this sensitivity to help produce random numbers. They also capitalized on another aspect of light: The exact number of photons emitted by a source at any instant is fundamentally unpredictable.

Bruno Sanguinetti and his team used an 8-megapixel camera in a Nokia N9 smartphone to take a picture of a light-emitting diode. The camera's image sensor recorded the number of photons hitting each pixel, recovering a slightly different number each time due to quantum uncertainties. The scientists then turned these inherently random photon counts into strings of random numbers suitable for creating cryptographic keys.

After one of the random strings of digits is created on the phone, the digits would be sent to the other partner involved in the transaction (that is, the buyer or seller). The digits would function just like the encrypted numbers used today in credit card transactions. Only these would be even more secure because they'd be grounded in quantum uncertainties. — KATHERINE KORNEI

Oldest Sperm Is No Shrimp

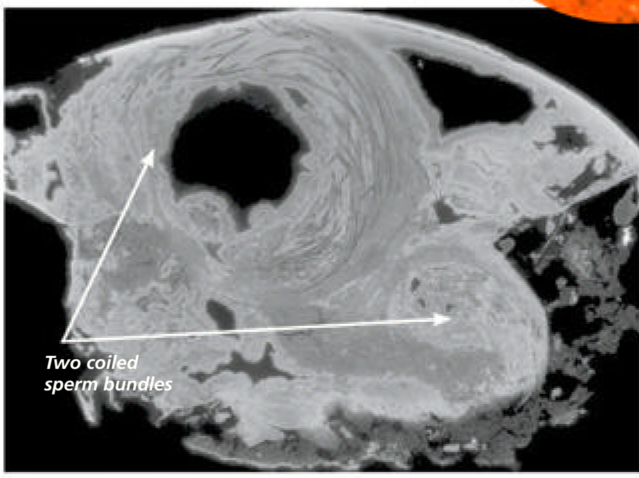
Ancient ostracod had long, and long-lived, sex cells.

German biologist Renate Matzke-Karasz beamed at the virtual fossil slices on her iPad. "There are definitely internal structures in this animal, and perhaps even sperm!" she emailed retired Australian micropaleontologist John Neil, wanting him to be the first to know. It would take five more years to confirm, but Matzke-Karasz was actually looking at the oldest petrified sperm in the world.

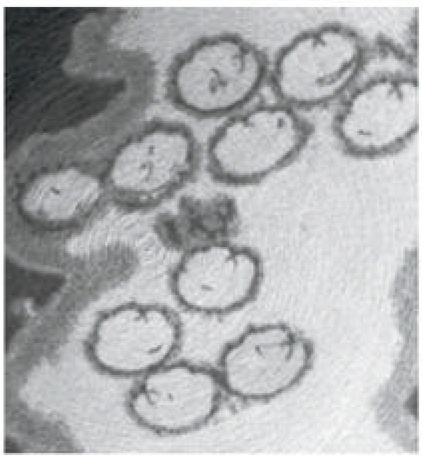
The fossil was a 17-million-year-old ostracod, or mussel shrimp. It was one of nearly 800 specimens that Neil had painstakingly handpicked from sediment between 2007 and 2010. Such fossils usually just include the animals' hard shells, not preserved soft body parts such as inner organs or sperm. But Neil's samples came from a freshwater cave in Riversleigh, Australia, where millions of years' worth of bat droppings left the sediment rich in phosphate, which petrified the ostracods' soft parts.

"I thought that other body parts and organs might be preserved," Neil says, "but the details were much greater than expected." However, while he was familiar with their hard parts, Neil didn't have much experience with analyzing ostracods' softer tissues. He needed collaborators to fully understand his find.

Matzke-Karasz read his appeal in the 2009 issue of *Cypris*, a newsletter for ostracod researchers, and when Neil sent the data, she was impressed. "We were smashed by what we saw and immediately had the feeling that we should look inside," she recalls. The European Synchrotron Radiation Facility in Grenoble allowed her to do just that.



Clockwise from top left: A close-up view of a 17-million-year-old ostracod via electron microscope. Ostracods are a type of crustacean, similar to shrimp, that thrive to this day. By imaging inside the fossil, we can see the remains, coiled in two tight bundles, of the oldest petrified sperm in the world.



A cross section of the bundles of individual sperm cells reveals their structure.

The scanners revealed the creatures' sperm — along with sperm pumps and female canals and seminal receptacles — coiled up in the ostracods' double reproductive system. (Males have two penises and females have two vaginas.) And at about 1.3 millimeters, the uncoiled sperm were relatively gigantic, longer than the ostracods' bodies. Some insects and marine creatures evolved such larger-than-life sperm to block out competitors during mating. "I've run out of superlatives," Neil says. "They are amazing in terms of the level of detail."

— KAREN EMSLIE

DID YOU KNOW? Thirty-three years — that's the age a female white shark reaches sexual maturity, according to a new study. Earlier research estimated Miss Jaws started breeding at 7 to 13 years old. The new finding will have a big impact on conservation strategies aimed at protecting the slow-growing apex predator.

ALL IMAGES: RENATE MATZKE-KARASZ

Ask Discover


ANSMET team members collect meteorite samples near the Transantarctic Mountains.

KATHERINE JOY/UNIVERSITY OF MANCHESTER

Q I've heard that more meteorites fall on Antarctica than any other continent. Is that true? And if so, why?

— Philip Meyer, Los Angeles

A Researchers recover more meteorites from Antarctica than anywhere else, but it's not because more fall there. Meteorites land everywhere with almost equal probability — it's the Antarctic conditions that make the difference.

Many meteorites contain high levels of metallic iron, so if one falls in a humid jungle climate, the combination of moisture and oxygen will corrode it. In Antarctica, a dry desert, the likelihood of corrosion drops significantly, meaning more rocks and more pristine samples.

Meteorites are also easier to locate in Antarctica partly because of the contrast between dark rocks and white ice sheet, says Ralph Harvey, principal investigator of the U.S.-led Antarctic Search for Meteorites (ANSMET) program. And since few rocks naturally form on the ice sheets, the majority of Antarctic rocks collected are extraterrestrial. Even when researchers hunt near the region's mountains, which contain lots of terrestrial rocks, meteorites' descent from space rounds their jagged corners and gives them a distinct, burnt outer coating, making them easier to spot.

The biggest reason, though, is ice flow. Sometimes mountains or other obstructions below the ice clog the East Antarctic ice sheet's path to the sea. If the sheet stays in one spot long enough, strong winds and sunlight can evaporate the top layers and reveal deeper, older ice — and large meteorite concentrations. ANSMET teams working near the Transantarctic Mountains have found more than 20,000 samples since 1976, most from unknown origins. – BRENDA POPPY

Visit **DiscoverMagazine.com/Ask** for more answers. To submit a question, send an email to **Ask@DiscoverMagazine.com**

Out Like a Light

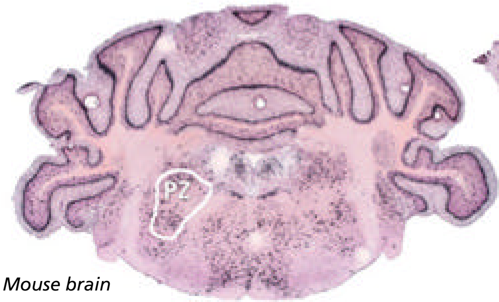
A newly discovered brain area could help us fall fast asleep, sans sedatives.

Trouble sleeping? Your brain's parafacial zone may not be doing its job. When this region was activated in mice, they fell into a deep sleep, no matter the time of day, background noise or presence of nosy researchers.

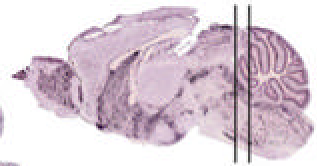
Harvard Medical School neuroscientist Patrick Fuller and his team not only discovered this cluster of neurons in the brainstem, they created an elegant "remote control system" to activate select neurons inside it.

Fuller's team started hunting for such a cluster, or "sleep node," a decade ago but didn't find it until 2012. After zeroing in on the likely site, they tested its function by destroying the cluster in mice. The animals became insomniacs, indicating the node controlled sleep.

To confirm their initial findings, the team developed a multistep process built around creating a chemical key to turn sleep on and off in the mice. First, they used mice that had a genetic modification in neurons that produce gamma-aminobutyric acid (GABA), a snooze-inducing neurotransmitter. Specifically, the researchers engineered these GABA neurons to copy DNA from viruses. They then gave a non-pathogenic virus DNA that contained instructions to create a receptor for a drug — derived from an anti-psychotic — that had no effect in mice.



Mouse brain



Cross-section location

Patrick Fuller and his team found that activating neurons inside the newly discovered parafacial zone (PZ) can put mice into a deep sleep almost instantly.

After Fuller and his team injected the virus into the parafacial zone, the genetically modified GABA neurons could copy the viral DNA that would allow them to create these receptors for the drug. If the team's plan worked, the drug would act like a key, fitting only into the receptors of the GABA-expressing parafacial zone neurons and turning them on. So if the mice that got the drug fell asleep, the team would know for sure that these neurons were responsible for their slumber.

Sure enough, the mice fell asleep almost immediately. "We went, 'Holy smoke!' … It was beautiful, deep cortical sleep," Fuller says.

The discovery, published in *Nature Neuroscience*, may lead to better sleep aids that target neurons more selectively, potentially eliminating side effects such as next-day drowsiness. – TEAL BURRELL

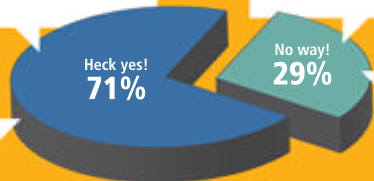
WEB

De-Extinction

In our March issue, we wrote about the efforts of some scientists to bring extinct animals, such as the woolly mammoth, back to life. The technology is nearly advanced enough. But should we do it?

"Carefully bringing extinct animals back to life is no more dangerous than the random products of natural evolution which is constantly going on."

"We are better off trying to save animals in danger of extinction now than trying to bring back those that are already extinct."



"It seems like a good way to connect with the past of our planet and learn more."

"Most of the habitats that these animals lived in no longer exist. Even if we resurrect them, where are we going to put them?"

We asked you on our website; weigh in at **DiscoverMagazine.com/Extinct**

QUICK HIT

You're Stressing Me Out

It's the ultimate in self-defeating behavior: Male chimpanzees compete so fiercely for the attention of fertile female chimps that they stress the females into infertility. A *Behavioral Ecology and Sociobiology* study found female chimps' urine showed lowered C-peptide levels when dealing with harassment and aggression from the jealously competing males, a symptom of several reproductive disorders that would prevent the chimps from conceiving. – ELISA NECKAR

FROM TOP: JAY SMITH; ALLEN INSTITUTE FOR BRAIN SCIENCE/ALLEN MOUSE BRAIN ATLAS AVAILABLE FROM MOUSE.BRAIN-MAP.ORG; ALISON MACKEY/DISCOVER

"TV Ears saved our marriage!"

- Darlene and Jack B., CA

The Voice Clarifying TV Ears Headset is specifically designed for clear, distinct, TV listening, without turning up the volume. With TV Ears wireless technology, you set your own headset volume and tone, while other TV listeners hear the television at a volume level that's comfortable for them. You can even listen through the headset only and put the TV on mute if the situation calls for a quiet environment…maybe a family member is sleeping in the next room. Or perhaps you are the only one who is interested in listening to the ballgame.

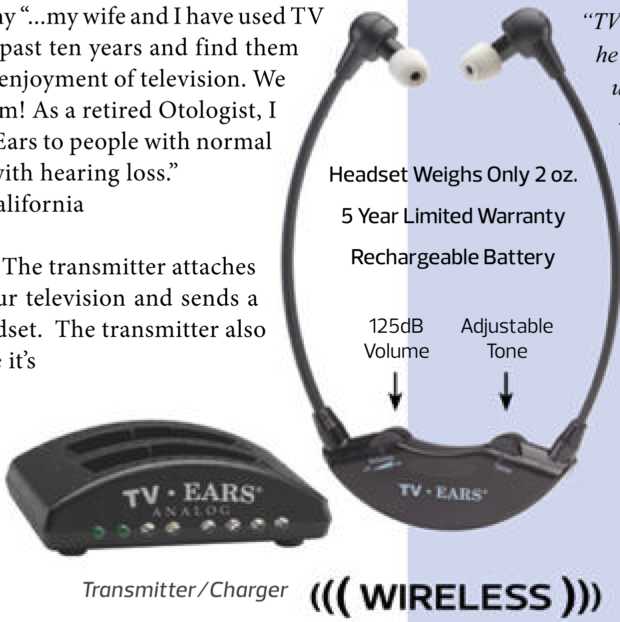
Doctor Recommended TV Ears! Proprietary Voice Clarifying Circuitry® makes words easier to discern and reduces background noise so television dialog is understandable. That's why "...my wife and I have used TV Ears almost daily for the past ten years and find them an invaluable help in our enjoyment of television. We would not be without them! As a retired Otologist, I heartily recommend TV Ears to people with normal hearing as well as those with hearing loss."
- Robert Forbes, M.D., California

TV Ears is Easy to Use! The transmitter attaches to the audio ports on your television and sends a signal to the wireless headset. The transmitter also charges the headset while it's not in use. There is no complicated technology to understand and no expensive batteries to replace…just sit down and enjoy the show!

New Special Offer!

Hear television dialog clearly without disturbing others with loud TV volume!

"Now my husband can have the volume as loud as he needs and I can have the TV at my hearing level. "TV Ears" are so comfortable that Jack forgets he has them on! He can once again hear and understand the dialog."
- Darlene & Jack B., CA



Risk Free Trial. TV Ears 5.0 Analog comes with a 30-day risk free trial. If you're not completely satisfied, return it for a full refund of the purchase price.

TV Ears 5.0.......~~$129.95~~

Special Offer

Now $59.95 + s&h

For fastest service, call toll-free between 6am and 6pm PST Monday through Friday.

1-800-379-7832

or visit

www.tvears.com

Please mention **Promotion Code 35465**

TV·EARS®

Voice Clarifying TV Ears Headset

- Over 2 Million Satisfied Users
- Volume up to 125 decibels
- 5 Year Limited Warranty
- TV dialog is clear and understandable

September 2014

Our Black Hole Skips a Meal

A wandering gas cloud escapes uncertain doom in our galaxy's center.

Last year, astronomers turned to the supermassive black hole at the center of our galaxy to watch it tear apart a dusty gas cloud called G2. It was an event widely anticipated, including in *Discover* ("To the Edge and Back," September 2014, "When a Slumbering Monster Awakens," April 2014 and "Our Black Hole Lights Up," January/February 2014).

The discovery of G2, which was estimated to have the mass of three Earths, was announced in January 2012 by Stefan Gillessen of the Max Planck Institute for Extraterrestrial Physics. Gravity from the black hole, called Sagittarius A*, already had begun stretching G2, Gillessen's team said.

The gas cloud was expected to make its closest approach in early 2014, plowing through the hot, magnetic plasma that surrounds the black hole. G2 would stretch like soft taffy and glow in X-rays, and some of the gas would spiral down the black hole, spewing radiation as it did so. This was a chance to watch Sagittarius A* dine — a rare show.

But there was no such spectacle.

UCLA's Andrea Ghez and colleagues had long expected such a flop. Since August 2013, they have argued that G2 isn't just a cloud, but instead a star shrouded in gas and dust. That would make G2 anywhere from 100,000 up to 1 million times more massive than what Gillessen's team thought, and thus Sagittarius A* would have a harder time pulling material off the object. If that's the case, it's no wonder the galactic center didn't light up.

But is G2 really a star hiding below gas and dust? Gunther Witzel, a member of the Ghez team, says they don't know conclusively. The way to find out is to watch how G2's orbit evolves on its trip through the galactic center. A starlike G2, Witzel says, would barrel through the hot plasma near the black hole, staying on its extremely elliptical 300-year orbit. But a cloudlike G2 would feel a drag, like a feather moving through air on Earth, says Ann-Marie Madigan of the University of California, Berkeley, who's not affiliated with either team. That drag would tilt and shrink the gas cloud's orbit while also possibly tearing apart the cloud.

Madigan expects at least three to five more years of observations before scientists can say with certainty what G2's orbit does — and what exactly G2 is. —LIZ KRUESI

Orange Is the New Maize

"I was the only one doing it," researcher Torbert Rocheford explains demurely when asked about the expertise that had the government knocking on his door in 2001.

Rocheford, a plant geneticist at Purdue, drew the attention of the U.S. Agency for International Development (USAID) for his research on variations affecting provitamin A carotenoids — naturally occurring plant pigments that our bodies can convert to vitamin A — in maize. Working with USAID and later HarvestPlus and the National Science Foundation, Rocheford has used natural breeding techniques to pioneer high beta-carotenoid orange corn.

Torbert Rocheford bred his nutrient-rich orange corn naturally.

PURDUE UNIVERSITY/TOM CAMPBELL

The bright-orange corn could help children in sub-Saharan Africa, where nutritionally inferior white corn is a dietary mainstay and thousands of vitamin A-deficient children go blind each year.

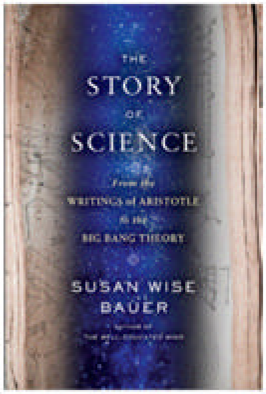
"Yellow corn is culturally unacceptable to some — it's fed only to animals — so orange maize is fresh and untainted by that perception," says Rocheford. "And it could provide twentyfold of vitamin A."

Other high beta-carotene root vegetables, such as carrots and sweet potatoes, don't grow easily in some African regions, so orange corn has the best chance of taking root and becoming a standard crop.

Consuming the new maize also could prevent vision deterioration caused by macular degeneration in the elderly. One variety may be available in the United States by 2016. – JIM SULLIVAN

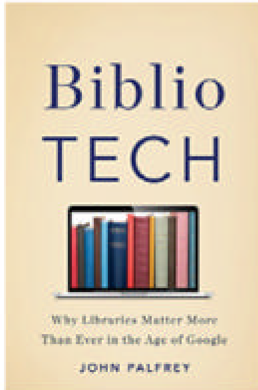
THE CRUX

BOOKS



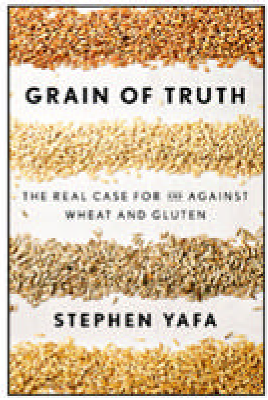
The Story of Science
By Susan Wise Bauer

The touchstone texts of science were not written in a void. Historian Bauer introduces readers to the stories behind the words of some of history's most radical thinkers and theorists. Alfred Russel Wallace, for instance, ill and forced to lie in bed for hours a day with "nothing to do but think," developed a theory of natural selection at nearly the same time as Charles Darwin. From the work of Hippocrates to Isaac Newton to Richard Dawkins, Bauer dumbs nothing down but makes complex topics comprehensible in just a few pages apiece. The results are accessible as a companion book with individual snippets on specific publications, or as an overall tour through the history of science.
—ELISA NECKAR



BiblioTech
By John Palfrey

From a bank of computers at a small-town library to mammoth case-law books piled on wooden tables at a university, today's libraries must straddle the analog and digital worlds. Palfrey argues for a national knowledge network, hinging on what he calls — in a positive way — the hacking of libraries. How do we move collections online while also staying true to libraries' century-old mission as vital community spaces? Look to the vast New York Public Library's digitization effort, as well as the Boston Public Library system, which has collaborated on modernization efforts with towns across Massachusetts. Now, says Palfrey, we just need capital: a modern-day Carnegie to help preserve libraries as digital platforms for ideas. —BECKY LANG



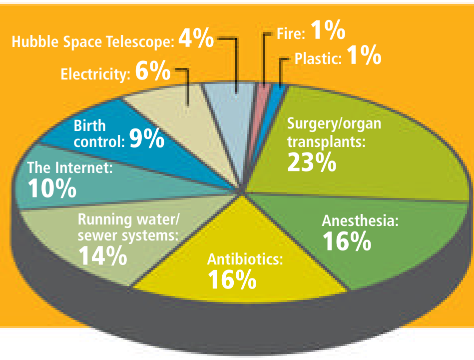
Grain of Truth
By Stephen Yafa

Is there any other mainstream foodstuff so maligned as wheat has been of late? What's worse, the actual science too often gets lost in the pop culture circus dominated by publicity-hungry hucksters and companies pushing gluten-free products full of chemical thickeners and starchy substitutions. Fortunately, Yafa is here to separate, uh, the wheat from the chaff, taking on everyone from anti-wheat advocates to geneticists and old-school artisan bakers. Yafa's background as a novelist and playwright comes through in his lively pacing and witty asides, but it's his commitment to cutting through the hype and hokum that makes *Grain of Truth* so compelling.
—GEMMA TARLACH

WEB

History's Best

We asked you on Facebook: What scientific advancement, from any point in history, are you most thankful for today? Here's what you said:



PIE CHART BY ALISON MACKEY/DISCOVER

Crime Scene Scavenger

Vultures help forensic experts with CSI research.

Kate Spradley slips blue hospital booties over her leather flats before stepping through the double security gate of a high fence surrounding a 26-acre outdoor research area on the Freeman Ranch in San Marcos, Texas. With her shoes safely covered to avoid contaminating the scene, she walks up to the cadavers laid out in the tall grass and notes the broken ribs and shattered eye sockets, the remains picked over by vultures.

Spradley is a biological anthropology professor at Texas State University, owner of the Freeman Ranch. She collaborates on her fieldwork there with Michelle Hamilton, a forensic anthropology professor also at Texas State. The two are trying to provide more accurate information in death investigations by studying how vulture behavior, combined with weather and geography, can modify human remains.

Vultures expose bones to rapid weathering and carry remains beyond the body's immediate location. These factors, sometimes missed by investigators and CSI types, can alter time-of-death estimates. Indeed, the duo's first 2011 study showed that vultures took roughly a month to locate a planted human body but picked it clean in just five hours. Now, they're expanding that research.

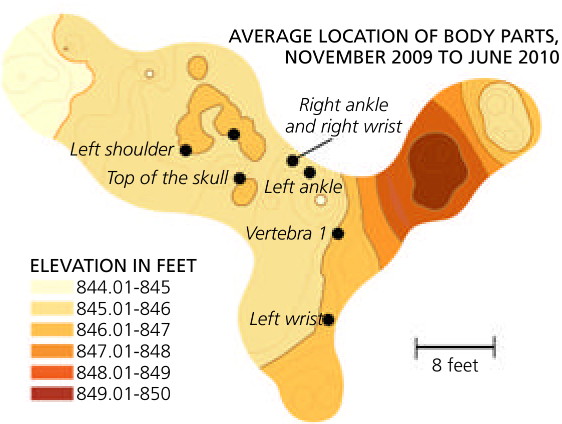
The current study, which they hope to publish this year, examines eight donated bodies in various micro-environments, mimicking possible crime scenes, throughout the Freeman Ranch field. Some remains lie on hard ground with minimal grass coverage, while others are partially or fully shaded under native plants, such as juniper trees.

Using motion-activated cameras and detailed field notes, Spradley and Hamilton documented vultures' feeding habits, including how long they take to locate remains. The researchers also construct detailed maps to document how the birds distribute remains across different sites.

"If the vultures scatter the bones in a very predictable environment," Spradley notes, "then we can educate law enforcement … on how to do recovery [and] where to look."

An accurate time of death or recovering enough of a body for a successful identification could make all the difference to a family of a missing child or a defendant in a murder trial. It's truly a matter of life and death.

—CHELSEA BIONDOLILLO



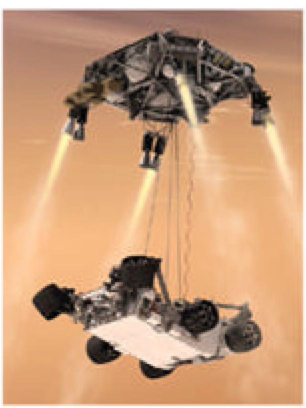
TOP: TOM VEZO/MINDEN PICTURES/CORBIS. BOTTOM: JAY SMITH AFTER M.K. SPRADLEY, ET AL./FORENSIC SCIENCE INTERNATIONAL 219 (2012) 57–63

Curiosity: We Have a Problem

A NASA engineer discovers a last-minute error with just days to spare.

In 2012, the Curiosity rover pulled off a spectacular landing on Mars as the whole world watched. But it was almost not to be. Just days before the landing on a Sunday in early August, NASA Chief Engineer Miguel de San Martín discovered an error. His team placed the spacecraft's Inertial Measurement Unit, an essential instrument for landing, in the wrong place, a few inches above where the landing software expected it.

Maybe the mistake wouldn't affect anything, but it could destroy the multibillion-dollar rover upon landing. With the clock ticking, San Martín and the rest of the team in Pasadena, Calif., had to help NASA figure out a solution: do nothing and risk a crash, or send a special programming command to the spacecraft and hope it doesn't have any nasty consequences.



NASA used a unique "sky crane" system to lower the Curiosity rover to the Martian surface.

IN HIS OWN WORDS

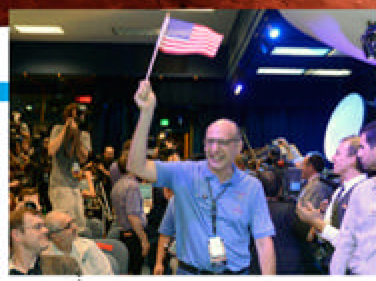
I went to see Pete Theisinger, the project manager, and I explained the error, taking full responsibility. We took it to the board of experts that deals with these things, and they voted for "no change." I felt relieved that it was over.

But that night, I started thinking. Did we consider all the aspects of this thing? I got cold feet. In this business, you need to be paranoid to be successful. You have to assume that an error could be the tip of an iceberg of a bigger problem. I didn't sleep.

So, it's Friday. I go back to Pete, and we agree to have another meeting Saturday morning to make the final decision. We worked that whole night, filling whiteboard after whiteboard with equations. I thought I'd actually be enjoying getting closer to the landing, but I just wanted to make a big hole and bury myself.

It's 10 a.m. Saturday, just one day before landing. The small room is full of upper management, and we hear that NASA headquarters in Washington was told about this issue. Most people were voting "no change," but when Pete's turn came, he said, "I want the change," overruling everybody. Our equations convinced him. There was grumbling, with some of the other members openly disagreeing and trying to change Pete's position, but they couldn't.

We had another meeting, this time with people from headquarters. I'm feeling very small, walking with my tail between my legs. So Pete tells the story, but now everybody votes unanimously in favor of



The Curiosity rover's descent on Mars (illustrated at top) was a success, thanks in part to the engineering efforts of Miguel de San Martín (above).

sending the software fix.

Pete looked at me and said, "Miguel, excellent job." I was shaking at that point because I felt that I let him down. Pete told me that "it was excellent because, first of all, you found it and got to the bottom of it; secondly, you came and told me about it." I felt relieved and was proud of being part of a culture that promotes openness. We sent the programming fix to Curiosity that night. The next day, landing went fantastically well.

— AS TOLD TO MELINA PARIENTE

FROM TOP: NASA/JPL-CALTECH; MICHAEL NELSON/EPA/CORBIS; NASA/JPL-CALTECH

Anomaly From Above

With the discovery of fast radio bursts, astronomers once again navigate the path from weird result to verified science.

BY **YVETTE CENDES**

Duncan Lorimer will never forget the moment he stumbled upon one of the great new mysteries in astronomy. The Australian radio astronomer at West Virginia University had asked an undergraduate, David Narkovic, to comb through pulsar survey data from the Parkes Observatory in Australia. One fateful day in 2006, Narkovic walked into Lorimer's office with evidence of an unusual observation: a pulse of radio waves from the sky unlike any seen before. It was among the brightest observations ever in radio astronomy, originating from billions of light-years away, and it lasted just a few milliseconds. "I was speechless," Lorimer recalls. "To be honest, I didn't know what to make of it."

Duncan Lorimer

Lorimer and Narkovic had uncovered the first fast radio burst, or FRB. It was a total surprise to them; the idea of radio wave bursts had been abandoned after scientists in the '70s and '80s failed to locate such signals. Only a handful of them (11 at last count) have been observed since their discovery nine years ago, and they remain unique. Many astronomers think they come from outside the galaxy, but beyond that, their origins remain mysterious. As novel as FRBs are, however, they are just the latest example of a sporadic but always exciting moment in science: an unexpected discovery of an anomaly in the expected data.

ANOMALY ANALYSIS

Although each unusual scientific discovery is unique, different disciplines of science process these anomalies similarly. The physicist and philosopher of science Thomas Kuhn first advocated the importance of such unexpected discoveries in the 1960s. Scientific progress is not a linear development of accepted theories, he argued, but instead relies on such anomalous discoveries to move the field forward. When enough accumulate from experiments, a field will enter a period of crisis, which often leads to a fundamentally new understanding of the field, known as a paradigm shift. Science is filled with examples of paradigm shifts throughout its history, such as the switch from Newtonian to Einsteinian physics, the rise of evolution to account for the variety of life and the acceptance of plate tectonics to explain the movement of continents over time.

In astronomy, paradigm shifts typically come from an unexpected signal in the sky. Steady pulses in the 1960s yielded the unexpected discovery of pulsars — the city-size neutron stars that Lorimer sought when he stumbled upon FRBs. Similarly, gamma ray bursts can originate from among the most violent events in the universe, such as the collapse of a massive star, but they were only serendipitously discovered by researchers monitoring nuclear proliferation on Earth during the Cold War.

Kuhn revolutionized how scientific anomalies are viewed today, but it's still not so simple. "Most historians and philosophers of science, although they like the thrust [of Kuhn's argument], don't buy it all," says Alan Rocke, a science historian at Case Western Reserve University in Cleveland. "There are still many disagreements about the details." In reality, history is far messier. Some paradigm shifts take a long time before a theoretical framework emerges, and sometimes anomalies lie dormant for decades or even centuries before being accepted and changing the course of science. Critical scholars argue that a Kuhnian world defined by sudden shifts is too simplistic, and that in reality things play out differently under different circumstances.

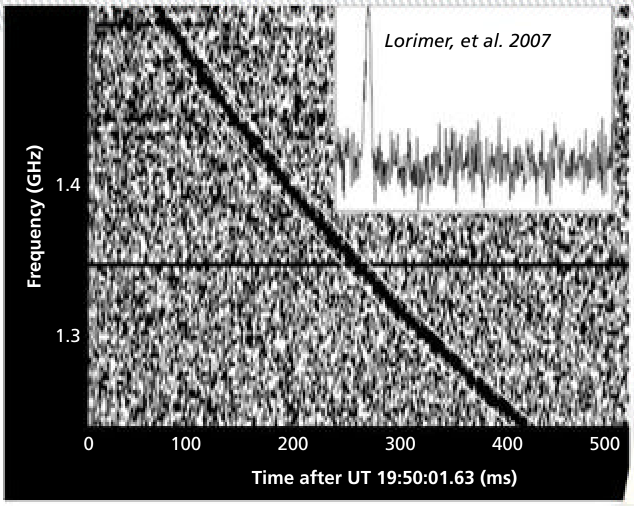
Parkes Observatory

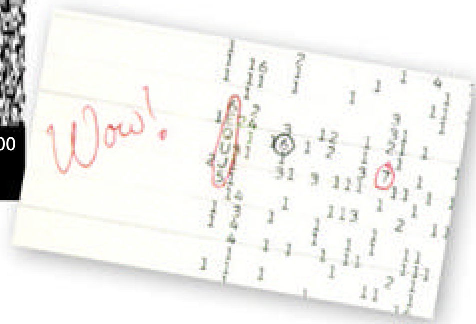
Kuhn's view also can leave too casual an impression of scientific progress. Look no further than the term *paradigm shift* becoming a corporate buzzword with little nonscientific meaning. Rocke emphasizes that serendipitous discoveries do not just pop out of nowhere. "It's similar to what Louis Pasteur said: 'Chance favors the prepared mind,'" he says. The discoveries of super glue,

LEFT: WVU UR NEWS PHOTO/GREG ELLIS. RIGHT: SHAUN AMY/CSIRO/NASA/JPL

Teflon and saccharine are all "lucky breaks" that actually came from determined chemists in the laboratory. "If you find something odd, it usually happens when you are obsessively engaged," Rocke says. "You are focused, you are fiddling, and you only notice because you know what *should* happen."

And indeed, that first "Lorimer burst," as it was known before the discovery of other FRBs, may have gone unnoticed if he hadn't been deeply interested. But which way would this anomalous signal go? Was it the first step on the path to a paradigm shift in radio astronomy, similar to pulsars or gamma ray bursts? Or were Lorimer bursts a dead end?





The first fast radio burst (left) jumped out from the data at researchers, who struggled to explain it. Astronomy has often made sense of such anomalies, but some (like the "Wow!" signal from 1977, below) remain mysterious.

FROM ERROR TO ANOMALY

Lorimer soon enlisted friend and collaborator Matthew Bailes, a pulsar astronomer at Swinburne University of Technology in Melbourne, to help make sense of that one FRB. Bailes' inclusion resulted in new insights on the pulse's shape, its evolution over time and the vast, extragalactic distance it overcame. Bailes even secured additional observing time at Parkes Observatory for follow-up observations. Even after a week combing the original spot in the sky that first FRB came from, they couldn't find any other signals.

A second FRB remained elusive for years, both at Parkes and other observatories, leading many astronomers to speculate whether the FRB anomaly was real. One particular concern was that the FRB might have originated from nearby thunderstorms, a particularly mundane explanation. Further, radio astronomy is a field with several cases of unexplained anomalous signals. For example, 1977's "Wow!" signal was a one-time radio burst lasting several minutes that bore the profile of a potential signal from extraterrestrials (hence its designation, coming from an excited researcher's notes). But no such signal was ever observed again. Without further observations, it is impossible for astronomers to classify it as anything more than a meaningless anomalous signal.

Eventually, patient searching did yield other FRBs, and astronomers slowly began to take them seriously as a scientific phenomenon. The biggest hurdle at this point was that only one observatory, Parkes, had ever seen the flashes. Without a second telescope's observation, it meant FRBs could still be nothing but human interference or a local atmospheric phenomenon rather than a new discovery in radio astronomy. After all, in Kuhn's framework, an anomaly is a problem without explanation; knowing an FRB from Parkes could just be local interference kept FRBs at the non-anomaly stage.

The clincher arrived in early 2014 when a team at Arecibo Observatory in Puerto Rico announced they'd seen an FRB. That two telescopes on opposite sides of the planet observed the same phenomenon won over many skeptics. "We now know it's not a farmer's electric fence," Bailes dryly observed, "unless they maybe have the same model fence in Arecibo." FRBs finally entered new scientific territory: an anomaly looking for an explanation.

SEEKING THE ANSWER

Now that FRBs have crossed over from strange oddity to real discovery, speculation has also ramped up on what creates them. "There are more ideas than bursts," explains Lorimer.

Proposals have ranged from stars shooting off enormous flares from their outer atmospheres to overactive magnetars — dense stellar remains with extremely powerful magnetic fields — but astronomers are hampered by an inherent imprecision with radio telescopes making it difficult to pinpoint a source. Lorimer's favorite idea has FRBs result from neutron stars colliding together far beyond our galaxy. "I have no support for that beyond romantic beliefs," he confesses. As a pulsar astronomer, he admits he is "a little biased" toward explanations involving them.

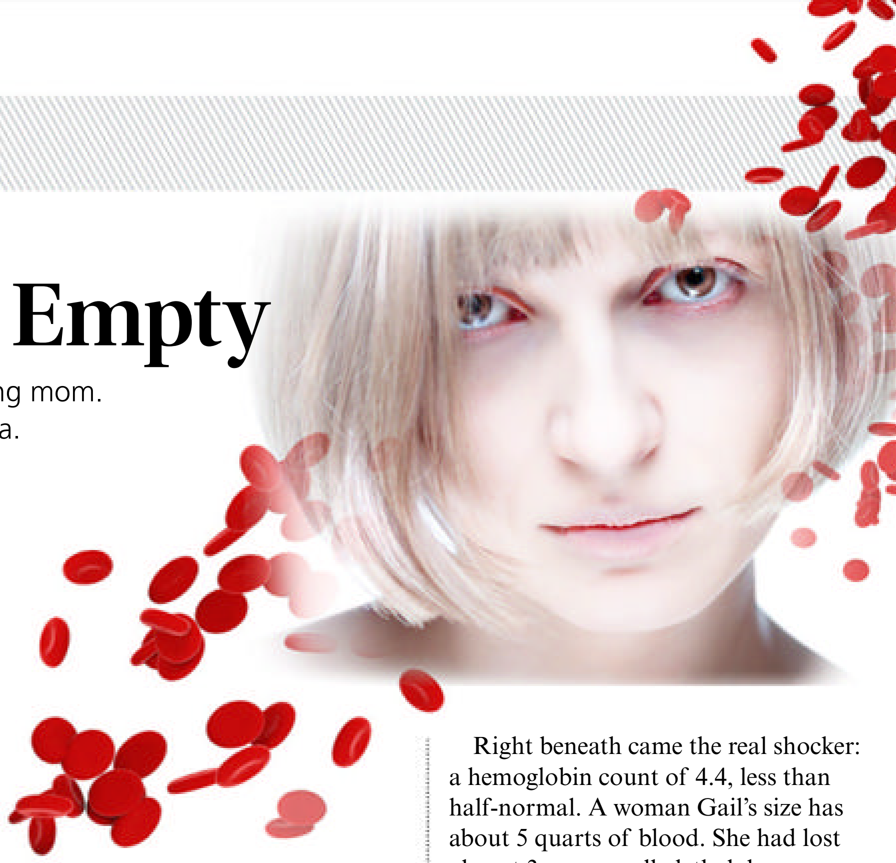
As the evidence and observations of these FRB anomalies continue to trickle in, however, astronomers are cautiously optimistic that they have stumbled not across fiction or technical error, but something much more novel. "It has been exciting to see it go from an oddity to something tangible," Lorimer says. It's a journey familiar to much of science. D

*When not doing something else, **Yvette Cendes** is a Ph.D. candidate in radio astronomy at the University of Amsterdam.*

Running on Empty

A fever and cough strike a busy, young mom. But this is no routine case of influenza.

BY TONY DAJER



WOMAN: STRAGA/SHUTTERSTOCK. BLOOD CELLS: TIGGER11TH/SHUTTERSTOCK

"You better see this one," my ER nurse, Elsa, urged. "Too pale, too pale."

I had already sent in Jeff, my medical student, for what seemed like a routine case: a 30-something woman complaining of cough, low-grade fever and fatigue for a week. I reread the chart: pulse 114 (a tad high), fever 100.4, good blood pressure and oxygen saturation near normal at 96 percent. This sure looked like the flu.

Hustling over, I found Jeff diligently noting his findings in a small notebook. The patient — a thin, blond woman wearing a slightly startled expression — did her best to answer him.

"Hello," I announced. "I'm Dr. Dajer, the boss."

"Hello, boss. I'm Gail," she riposted.

Elsa was right. Blond hair and fair skin notwithstanding, her complexion was bone white. "How long have you been sick?" I asked.

"About a week," she answered. "I'm a wimp, I guess, but this cough wasn't getting better." She paused to catch her breath. "I was in such a hurry. Had to run the kids to the babysitter's. Then the doctor's office. He sent me straight here."

The monitor showed decent vital signs, but every word cost her. Elsa had already hooked up oxygen and started IV fluids.

I signaled Jeff to place his stethoscope next to mine. The right lung was healthy; the breathing sounds were soft and sibilant. The left lung, though, sounded crackly and wet at the base. Jeff's eyes widened as he picked it up.

Easing out my earpieces, I said tentatively to Gail, "I think you have pneumonia."

"Oh, no!" she exclaimed. "Can I pick up the kids first? Is it contagious?"

Pneumonia was once called "the old man's friend" because it was said to strike the elderly with a relatively quick and painless death. But it kills young people, too. Jim Henson, the Muppets creator, succumbed in his 40s. Pneumonia, though often treatable at home with oral antibiotics, can run riot.

But Gail did not look toxic. She looked exhausted.

The X-ray came back. A dense patch clouded the left lung base. Jabbing a finger at it, I told Jeff, "Classic bacterial pneumonia. Probably pneumococcus."

He nodded solemnly. Then Elsa grabbed my arm: "Come."

We went over to her computer. Gail's blood counts jumped off the screen: The infection-fighting white blood cells topped 35,000. (Normal is up to 11,000.)

Jeff whistled. "That's a bad pneumonia."

Right beneath came the real shocker: a hemoglobin count of 4.4, less than half-normal. A woman Gail's size has about 5 quarts of blood. She had lost almost 3 — a usually lethal drop.

"Mycoplasma?" I blurted, suddenly not only concerned, but confused. No classic pneumonia, this.

FRIENDLY-FIRE FALLOUT

Mycoplasma pneumonia is an odd bug — one-fifth the size of a bacterium but bigger than a virus — that causes what's popularly known as "walking pneumonia." The usual X-ray picture is of wispy white strands throughout the lungs, not Gail's socked-in snowstorm.

In the 1950s, mycoplasma gained notoriety because it did not respond to penicillin as other pneumonias did, thus earning the sobriquet "atypical" pneumonia. There are many other mycoplasma species, as well as other non-mycoplasma "atypical pneumonias." Mycoplasma pneumonia needs to inhabit a human to survive, but unlike a virus, it can thrive outside a cell.

Adept at burrowing between the cells lining the upper respiratory tract, mycoplasma pneumonia usually only causes a nasty cough and the sniffles. The deeper lung tissues are typically spared, and no antibiotics are needed. Trouble begins when the bug ranges more deeply. Then it can unleash not only pneumonia, but also a hemolytic

anemia that stems from "friendly fire" — a mycoplasma protein so closely resembles one found on human red blood cells that anti-mycoplasma antibodies will blow up the body's oxygen carriers, too.

"That hemoglobin is insane!" Jeff whispered. "How can she still be talking?"

"She's compensated," I said. The loss of red cells had likely progressed over the past week, allowing Gail to adapt by pulling extra proteins and fluid into her bloodstream.

"But she still needs some red cells, right?" Jeff persisted.

"She most definitely does," I answered. "Any lower and she's in big trouble."

We trooped back in. Gail, all ivory skin and blue eyes, straightened to hear the verdict. Her husband had arrived.

"It is pneumonia," I explained. "The X-ray points to one type, but your blood work to another, one called mycoplasma."

Gail looked half-relieved; she hadn't been crying wolf.

"The good news is, the immune system makes antibodies to fight this infection. The bad, those antibodies can also target your red cells."

"What does that mean, doctor?" the husband asked, now grim-faced and hovering.

"It means you've lost a lot of blood. I'm amazed you were able to walk, much less carry your children. Besides antibiotics, we'll need to transfuse you, plus add steroids to rein in that immune response."

"Doesn't she need the immune response?" the husband asked.

"Yes, but if we don't modulate it, the antibodies will chew up any new red cells we give her."

"We have two kids, doctor," the husband continued. "Is this contagious?"

"Yes. Usually it only causes cold symptoms. There's no need for antibiotics unless it's pneumonia. Plus, there's no easy diagnostic test for mycoplasma. Are they OK?"

Gail piped up. "Runny noses, but no fever or cough."

"I'd sit tight and see your pediatrician," I advised.

I pulled Elsa aside. "Two units of blood now. Plus the antibiotics. Plus steroids."

"That hemoglobin is insane!" Jeff whispered. "How can she still be talking?"

She held up a small bag of IV medication. "Way ahead of you," she said.

Would the steroids rein in the antibodies fast enough? I worried the more red cells we transfused — like booster shots of a vaccine — the more antibodies would multiply.

The intensive care unit team arrived. Bob, an ace physician I've never seen sit down, glanced at Gail, heard me say, "White count 35, hemoglobin 4.4" and nodded: "We'll take her."

The look on their faces told me Gail and her husband understood: ICU equals very sick. Tamping down my own anxiety, I tried to reassure them.

"You're more than holding your own, but a lot needs to happen quickly. We can monitor you best in the intensive care unit."

REVVING BACK UP

Overnight, it took three units of blood to raise Gail's hemoglobin above scary. The next morning, her brave smile greeted me.

"Wow," I blurted. "You're pink!" Framed photos of two towheaded kids populated the room.

She beamed back and said, "I feel so much better."

The hemoglobin dipped again that evening, so another unit went in. Then the wayward antibodies retreated, and the antibiotics kicked in.

I called her a week after discharge.

"I guess I'm fine," she said. "Still dragging, though. Sorry, I don't mean to whine. I need to get back in shape."

Pulling up her discharge labs, I saw her hemoglobin had bounced back to 70 percent of normal.

Recent studies have shown it is best to transfuse to that level, then let the bone marrow replace the rest. But that takes six weeks.

"Did they explain that you're not back to normal yet?"

"I'm not sure," she replied.

"Your tank is still only two-thirds full. It's the safest way to go, but you won't be yourself for six weeks. So give yourself a break, eat meat, and get lots of rest. You're not Superwoman, you know."

I paused.

"But the closest thing yet." D

__Tony Dajer__ is director of the emergency department at New York-Presbyterian/Lower Manhattan Hospital. The cases described in Vital Signs are real, but names and certain details have been changed.

LORELYN MEDINA/SHUTTERSTOCK

Altered Voices

Detecting subtle vocal cues through speech analysis could lead to earlier screening and treatment for autism, depression, dementia and more.

BY **SUJATA GUPTA**

The baby is a few months old. His earliest cries are short, his lungs too small to produce the prolonged wail of a toddler. A few months later, he can pull in enough air to elicit a sort of chuckle. And by 6 months, he's trying out vowel-like sounds — *wuh*, *wuh*, *wuh*. Soon, he's combining consonants and vowels and repeating them. *Nyah*, *nyah*, *nyah*, he says with evident glee. The baby has begun babbling, as large a developmental milestone as sitting or standing.

Nobody learns to talk without babbling, says Gordon Ramsay, director of the Spoken Communication Laboratory at the Marcus Autism Center in Atlanta. But babies at risk of developing autism babble later than the average 6 to 9 months. Speech scaffolds the entire learning process, so missing those early vocal milestones can derail a child's cognitive development.

But today, autism is rarely diagnosed before age 2, and usually after age 4. So Ramsay has developed a vocalization analysis program — a sort of verbal blood test — to screen for at-risk babies. His long-term hope is that identifying children at risk of developing autism and intervening during those formative early months will prevent one of the disorder's most devastating symptoms. "I'm absolutely convinced that no [autistic] child needs to be nonverbal," he says.

New speech analysis tests could also help doctors screen for several other cognitive and mental health ailments, such as dementia and depression, that can be difficult to detect in their early stages. The programs analyze voice recordings, measuring acoustic characteristics such as pauses between words, intonation and pitch. They eventually "learn" to identify unusual vocalization patterns characteristic of specific disorders. Knowing these vocal biomarkers could change the screening process entirely.

Ideally, these tests could help identify disorders before full-blown symptoms manifest, says Emily Tucker Prud'hommeaux, a computational linguist at the Rochester Institute of Technology in New York. "Wouldn't it be nice to stop progressive cognitive impairments before they progress very far?" she says.

> "I'm absolutely convinced that no [autistic] child needs to be nonverbal." — GORDON RAMSAY

UNDERSTANDING SPEECH MECHANICS

In the early 1990s, when Ramsay was a young graduate student at Cambridge University in England, automated speech recognition programs (think Apple's Siri) just started to appear. The programs guessed at words and sentences based on the statistical probability of someone uttering a certain sound or phrase, akin to autocorrect on smartphones. Yet Ramsay wasn't interested in using the programs to develop new technologies; he was more interested in understanding the physics of speech,

JG_DESIGN/SHUTTERSTOCK/ALISON MACKEY/DISCOVER

such as how the mouth's motions create sound.

Humans use sounds and vocal gestures, such as pitch or talking speed, to convey information, according to speech perception theories. By building a speech recognition model that incorporated information about the biology of speech production, Ramsay hoped to test those theories using real-world data. In 2004 he joined Haskins Laboratories, a speech and language research center in New Haven, Conn., to look into developing such models.

While at Haskins, Ramsay met Ami Klin, then an autism researcher at neighboring Yale University. Klin was working with babies who had older siblings diagnosed with autism. Such younger siblings have a 1 in 5 chance of developing autism — 14 times higher than children in the general population. So Klin, who now directs the Marcus Autism Center, wanted to see how these younger siblings perceived talking faces.

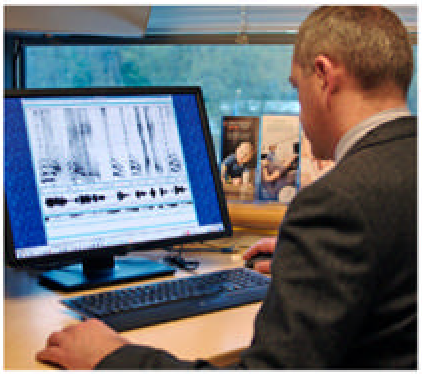
He asked Ramsay to explain how the mouth's shape affects the sounds we make, which piqued Ramsay's interest in testing his new speech recognition models on infants. Existing models, Ramsay explains, cannot recognize immature acoustic patterns, yet a model based on the biological patterns of speech, like his, should work at all ages.

Through their partnership, Klin eventually persuaded Ramsay to study the younger siblings to identify differences in their vocal interactions with the hope of one day screening for autism using vocalizations.

RECORDING IN THE WILD

Ramsay already knew about the pioneering work of Kimbrough Oller, a psycholinguist at the University of Memphis in Tennessee. Oller reported in 2010 that he had developed a customized algorithm to distinguish autistic toddlers from healthy children with a remarkable 86 percent accuracy,

This device, used once a month for an entire day, records babies at risk of autism. The audio is later run through speech analysis software.



Gordon Ramsay studies the software's analysis of a captured vocal interaction between an infant and caregiver.

MARCUS AUTISM CENTER (2)

in part, by isolating syllables and analyzing them for acoustic features, such as jaw and tongue movement.

Oller's work was groundbreaking, but he knows it can be pushed further. By 18 months of age, "we already have lots of ways of showing that a child is en route to developing autism," he says. What's really needed is a way of identifying even younger at-risk babies.

So Ramsay embarked on a five-year longitudinal study in 2012 to create a vocal development growth chart, similar to those doctors use to gauge a baby's physical growth. Every three months, trained clinicians conduct formal assessments of all the babies, and Ramsay observes the babies in the clinic once a month. He also captures all-day recordings of them once a month while they're at home or, as he says, "in the wild." His program then checks for conversational turn-taking between caregiver and infant, cry acoustics and sounds indicating babbling, like *pa* or *ba*.

Babies who score low on an initial voice analysis test would be further evaluated to determine what kinds of intervention, if any, they should receive. These tests would make autism screens more accessible than the one-on-one time with a trained clinician that's currently needed. But the real promise of screening with vocal analysis tests lies in their simplicity and affordability, Ramsay says: "It's just not possible to screen every child at risk with a $5,000 assessment." The vocal recorder Ramsay uses, by comparison, costs just $10. "I basically can reach anybody the USPS guy can reach," he says.

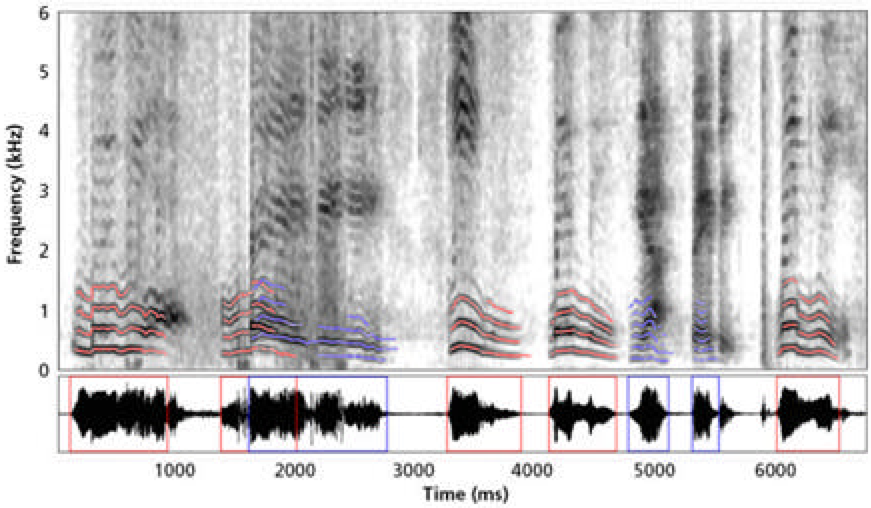
DIAGNOSING DEPRESSION AND DEMENTIA

Vocal screens could also help adults at risk for cognitive or psychiatric disorders who face similar challenges. For instance, researchers at IBM Research in Haifa, Israel, are developing a five-minute screening tool that uses voice recordings and computer analysis to identify people with mild cognitive impairment, a precursor to dementia.

In pilot studies in France and Greece, the tool pinpointed patients with confirmed mild cognitive impairment 80 percent of the time. The team recently launched a larger study in which participants will perform more vocal tasks to strengthen the technology.

Voice analysis could also help spot signs of relapse in those with psychiatric illnesses such as depression,

Mind Over Matter



The sound spectrogram above shows a typical infant-caregiver interaction. By tracking the harmonic structure of the voice, moments where infant (red) and caregiver (blue) are vocalizing can be automatically identified, labeled and separated from background noise. Important conversational cues, such as the intonations and resonances of each speaker's voice and the relative timing of their vocal interactions, can be extracted from the recording.

MARCUS AUTISM CENTER

bipolar disorder and schizophrenia, says Brita Elvevåg, a cognitive neuroscientist at the University of Tromsø in Norway. Elvevåg is developing voice analysis software that can tell if patients' mental states are worsening. If it detects a combination of telltale vocal changes — such as a patient talking faster or at a different pitch, or speaking less coherently — it would alert a health care provider.

Voice analysis could also help spot signs of relapse in those with psychiatric illnesses such as depression, bipolar disorder and schizophrenia.

AT RISK AND NOWHERE TO GO

But even if Ramsay successfully identifies babies showing signs of autism, the next step isn't obvious. "How do we go about putting in place support for families when there is no treatment [for very young children] yet?" he asks.

Fortunately, researchers are piloting early intervention programs. Connie Kasari, an educational psychologist at the University of California, Los Angeles, meets twice a week with families with children 12 to 21 months old who are at risk of autism. She encourages healthy skills, such as pointing or making eye contact. After two months, one 12-month-old boy who rarely smiled, vocalized or made eye contact with his parents said his first words, and his parents felt they could more easily interact with him. But the results need to be replicated, and Kasari isn't comfortable saying she prevented the boy from developing autism. If Ramsay can identify very early vocal warning signs, however, such early interventions hold considerable promise.

Ramsay plays me one more recording of the now 12-month-old baby boy. "Buuuh-bee," he says. "Baby," says his mom. "Baby," he repeats with perfect clarity. Ramsay suspects this mom, at least, has little reason to worry. D

__Sujata Gupta__ is a freelance science writer who lives in Burlington, Vt. Follow her on Twitter, __@sujatagupta__

Hooked on a Feeling

From smooth glass to rough sandpaper, tomorrow's HAPTIC SCREENS could create sensations as varied as real life.

BY **SUSHMA SUBRAMANIAN**

As he swipes his finger over the touch screen, Joseph Quintanilla senses a subtle bumpiness. Rubbing back and forth, he feels the roughness give way to what seems like a flat glass surface. "Yeah, I can feel it getting smoother," says Quintanilla, who is blind.

The touch pad in his hands displays a snowy, frosted window that his finger wipes smoother with every pass. It's an effect created in part by Ali Israr, an engineer at Disney Research labs. Israr specializes in haptic engineering, which focuses on applying tactile stimulation to our interactions with computers.


Ali Israr

The texture under Quintanilla's finger doesn't mimic the *exact* feeling of snow under fingertips — the temperature shifting, solid becoming liquid — but it does convey the feeling of a rough texture becoming smooth and even. Once Israr describes the image, Quintanilla immediately gets it. "Oh yeah, I can picture it now," he says. "That's very cool."

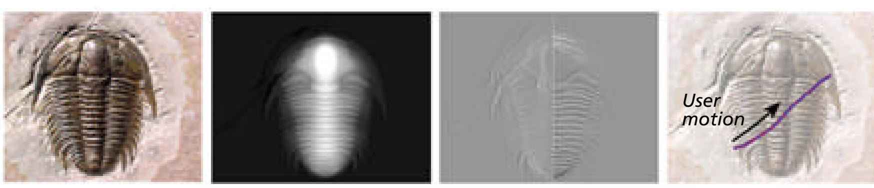
Quintanilla, who works at the National Braille Press as its director of major gifts and planned giving, is looking for a tool that could help blind children read maps and graphs when taking standardized tests. Currently, these students use sheets of paper with raised lines to represent images — a format essentially unchanged since the 1820s and increasingly costly to print.

Quintanilla heard about Israr's work on Disney's TeslaTouch, a flat screen that uses frictional forces to make users feel like they're interacting with images on it, and he decided to check it out to consider it for grant funding.

Israr is part of a community of researchers working to make touch screens more, well, touchable. Movements with our fingers across a flat screen have come to replace pressing buttons and keys on everything from ATMs to phones, and researchers now are working on the next frontier: adding tactile feedback to help enhance the feeling that users are interacting directly with the technology. Advanced touch screens like the TeslaTouch are on the cusp of widespread use, according to Israr. "It might seem crazy now, but I bet in 10 years it will just seem like, 'Of course that happened,' " he says. "It'll just become what we expect of our devices."

CAUSING A SENSATION

With his thick, black hair, round cheeks and his "work uniform" of a T-shirt and hoodie, Israr appears younger than his late 30s. He always knew he would be an engineer, but until he began his doctoral work at Purdue University, he had never heard of haptics. (From the Greek word meaning "to touch.") While there, Israr worked on a device called a tactuator — a machine that took audio recordings and translated them into movements felt by the fingers — to understand how to relay the sounds of various letters. Theoretically, it would help the blind communicate based on Helen Keller's famed Tadoma method, which allowed her to understand speech by placing her fingers on a speaker's lips and jaw line.



Left to right: To re-create the feel of a three-dimensional object, such as a trilobite fossil, the TeslaTouch team creates a depth map, from which they calculate a gradient field that tells the screen what kind of friction to use when a finger moves across the flat image.

Through his research, Israr came to understand the complications of communicating different types of touch through technology — vocal vibrations, gusts from breathing and jaw movement. He set about trying to imitate the sensations with machines. His research showed that users could understand far more sounds through touch than anyone had expected, but unfortunately, once Israr graduated in 2007, no one continued work on the tactuator. It remains just an idea and a prototype to this day.

After a postdoctoral stint at a haptics lab at Rice University, Israr got a job at Disney in 2009. In the long term, haptics could find uses in amusement park rides or gaming devices. At Disney, he started working under Ivan Poupyrev, a principal research scientist whose expertise had been in sensors and product design. (Poupyrev has since left Disney to work at Google.) Early in Israr's tenure, Poupyrev and a researcher named Olivier Bau built an early model of the haptic tablet hardware.

Poupyrev initially came up with the idea by accident the year before, when he was working as an engineer at Sony. Late one night, as he tried to assemble parts of a touch screen from a supplier while working on another product using tactile feedback, he mixed up the wiring instructions. Suddenly, when he slid his finger across the screen, he felt a rubbery sensation. At the time, Poupyrev was busy with other work, so he set aside the weird sensation for later.

When a restructuring at Sony shut down Poupyrev's product development, he joined Disney as principal research scientist. There, he bought similar materials — a glass plate covered by a transparent conductive sheet, itself

covered by a thin insulation layer — and tried to re-create the feeling.

In trying to understand the phenomenon, the team discovered a paper from 1953 written by a chemist named Edward Mallinckrodt that first described the technology, dubbed electrovibration.

Mallinckrodt discovered the phenomenon when he noticed that a shiny, brass electric light socket felt smoother when it was off than it did with the light burning. After a few years of experiments trying to figure out why, he realized that the thin insulating coating shielded the finger from being shocked but still carried electric current for the finger to notice the electricity running through the surface. This attracted the finger gently toward the surface, stretching its skin. While the force was too weak to detect when the finger was still, it created tactile resistance when the finger moved across the surface.

Within weeks, Poupyrev and Bau had replicated the sensation from Poupyrev's happy accident. They named it the TeslaTouch, after Nikola Tesla, who invented the alternating current that powered the device. Poupyrev knew they were onto something and brought on Israr, with his experience understanding people's perceptions of haptic information, to help determine how to convert those electrical forces into meaningful experiences.

A TOUCHING EXPERIMENT

To figure that out, Israr and the TeslaTouch team needed more data. They brought study participants into the lab to describe how it felt when Israr charged the screen with voltages of various frequencies and amplitudes. Participants were encouraged to describe the sensations using nouns: fur, silk, jeans, sandpaper. Low-frequency stimuli felt rougher, like wood and bumpy leather. High-frequency stimuli felt like smoother surfaces, such as paper and a painted wall. Generally, varying the amplitude did the same: High amplitudes felt smoother.

Combining the two produced even more sensations. A high frequency and high amplitude made the surface feel extra smooth, like a wall painted in latex. On the other hand, turning up the amplitude at a low frequency made the screen feel slightly sticky, like a motorcycle handle or soft rubber. One participant even said it felt like he was running his fingers through a viscous fluid.

The team now had a library of textures it could use to make the screen feel smooth, bumpy, rough or sticky. Next, they brainstormed tactile illusions that made use of those effects on the TeslaTouch. The bumpy feeling of a low-frequency current gave rise to a virtual computer mouse with a ridged scroll wheel. By progressively increasing amplitude at a low frequency, the researchers felt they could give the impression that users' fingers were sticking to the screen. They projected an image of three different-size weights. The biggest, the one with the highest amplitude, produced the stickiest sensation, so the friction that it created as a user moved it across the screen gave the impression of heft.

> **"It might seem crazy now, but I bet in 10 years it will just seem like, 'Of course that happened.' It'll just become what we expect of our devices."**

After a heavy snowstorm one weekend, the team came up with the idea of a frosted window being wiped clean, with each stroke increasing the frequency, making the surface feel smoother to the touch — the effect Quintanilla would feel in Israr's office.

Over the next several years, Israr and his colleagues traveled the world, presenting the model at technology conferences to build interest. While the technology impressed scientists and businessmen, they kept asking what else it could do. Creating textures on a screen was interesting, but could it display 3-D graphics or convey different sensations to different parts of a hand, truly mimicking the way we experience touch in our day-to-day lives? Israr decided to find out.

REACHING NEW PEAKS

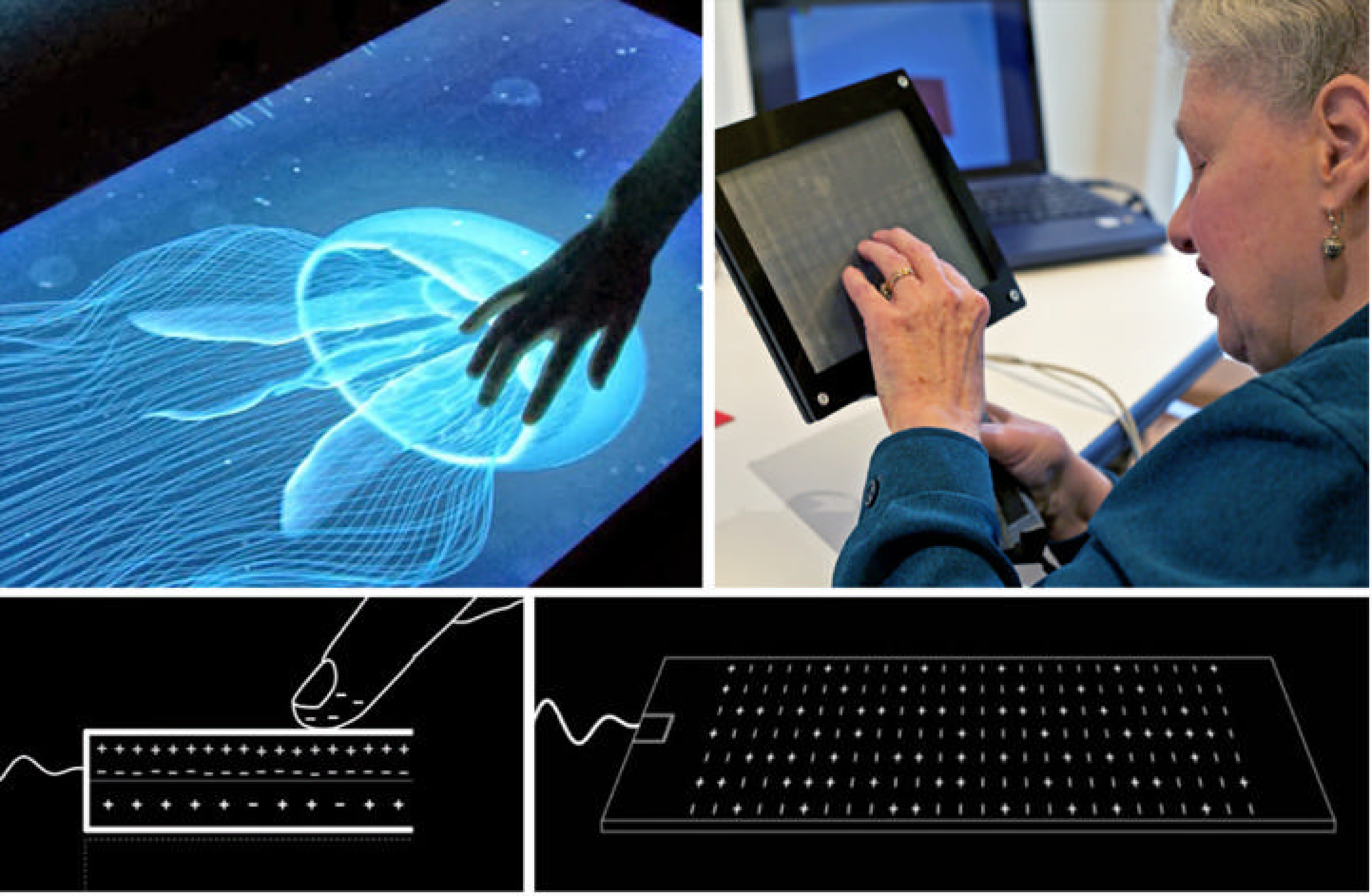
As he read up on the sense of touch, Israr learned that humans perceive dips and slopes on a surface primarily through the stretching of the skin. In places where a surface is raised, they experience increased friction on their finger. The opposite naturally occurs with a dip in the surface. Israr then surmised that a higher voltage, which would create more friction, would give the user the impression that the screen was pushing up against his finger, producing a 3-D effect. With that hypothesis, he went to work trying to create the perception of a single large bump on a flat screen.

Israr again turned to research subjects, asking them to feel a touch screen powered with varying voltages. Israr projected an image that looked like a bell photographed from above and asked test subjects what type of frictional pattern best matched the feeling they'd expect when they slid a finger over it. He tried turning the voltage off when users reached the top of the bump as well as matching the voltage to their perceived height of various parts of the image.

But neither effort felt right to users; the second one made most of them feel like the surface was raised but then plateaued. In the end, the pattern of electrovibration that felt to users most like the picture matched the frictional forces to the slope of the bump: the steeper the curve, the more voltage required to increase the friction.

While several other researchers could also create textures on tablet-size devices using vibration, Israr was the first to develop an algorithm for tactile rendering of 3-D features and textures on touch surfaces. Using the same theory he used to create his raised surface, Israr wrote an algorithm that allowed users to feel any "depth map," a computer graphic that conveys information about the distance and surface of the object depicted. It was a breakthrough for Israr and his team.

Israr thinks the next step will involve seeing if the device can provide different sensations to each finger of a user. This would allow for another level of 3-D tactile illusions: Each finger of a hand gliding across a desk would reach the



Clockwise from top left: A user "feels" the jellyfish in real time on a TeslaTouch haptic screen. Such technology could be a boon to the blind, as Louise Chuha, a board member of the Golden Triangle Council of the Blind in Pittsburgh, discovers for herself. TeslaTouch re-creates the sensation of texture by varying the electric fields on a touch screen. As a finger slides across, the difference in charge feels like friction.

ALL IMAGES: DISNEY RESEARCH

corner in succession; a piano keyboard app would allow users to feel a dip in several keys while playing a chord.

"The possibilities are huge if we could transmit signals to multiple fingers," Israr says. "Imagine what this could be used for. We could have the potential to create 3-D interfaces for the blind. We could feel clothing before we bought it online. We could transmit touch when talking on Skype."

HAPTIC ENDING

The potential application for a haptic screen is perhaps best shown through one of Israr's favorite illusions on the TeslaTouch. In his office, as Quintanilla handles the tablet, he comes upon an image of a rectangle on a grid, like something out of middle-school geometry homework. Israr guides Quintanilla's finger to the corner of the rectangle and asks him to drag it.

When Quintanilla moves his hand across the screen, the TeslaTouch provides a frictional force on his finger. The drag force is released just as the polygon's corner reaches another vertex on the grid, making it feel as if Quintanilla is snapping the corner of the rectangle into place. "OK, I can feel it releasing," Quintanilla says. "I just got it to a point, right?"

"Haptics can help make technology easier and more intuitive to use," Israr says. "I love this illusion because it shows the potential of this technology. We need feedback on our fingers to tell us how we're moving across the screen. Once the feedback is in place, it becomes easier to use the screen to create."

Quintanilla agrees. "What makes this different from other haptic devices I've tried out is that it's responding to my movements," he says. "I'm not just feeling something that's staying in one place."

Even though Quintanilla's hoped-for tool for the blind may be years away, technology that could enhance how we use gadgets in unimagined ways is on its way. Right now, Israr isn't too concerned about how the technology will end up being used. "Nobody really has a good idea yet of what it's good for," he says. "We want to build the interface, and we're curious what it will be used to create."

One of the earliest criticisms of touch screens was that our movements on them were imprecise. That's partly because there's no feedback to tell if our fingers are in the exact right place. If we have buttons we can feel, or textures we can sense moving, we'll be able to use them much more easily, Israr says.

"Haptics can help make technology easier and more intuitive to use," he says. "It can help people create." Once people can physically feel the images they're interacting with, there'll be no going back. **D**

__Sushma Subramanian__ is a Brooklyn-based freelance journalist whose book about haptics and what it's teaching us about our sense of touch is forthcoming from Algonquin Books.

MIPAN/ISTOCK

Tomorrow Never Was

A conscientious cosmologist rejects Einstein's notion that time is an illusion and the future's already written.

BY ZEEYA MERALI

George Ellis is not afraid to rock the establishment. In his youth in South Africa, his target was a recognizably corrupt and racist government. Now a cosmologist at the University of Cape Town, Ellis has set his sights on something more abstract: the flow of time itself.

First developed by Albert Einstein early in the 20th century, the orthodox view holds that the passage of time is an illusion. There is no difference between the past and the future — both are set in stone. Yet for Ellis, the philosophical implications of this mainstream theory do not simply run counter to our intuitions; he considers them dangerous because they rob us of free will and moral accountability. Ellis' scientific goal, motivated by his ethical views, is to put time back into physics, allowing the cosmos to create its fate and giving us the ability to change our destiny.

ORIGIN OF A COSMOLOGIST

Ellis refined his new theory of reality, in which time exists and the future remains unwritten, while on sabbatical at the University of Cambridge, the institution that during the 17th century boasted Isaac Newton, first as a student and later a professor.

In Newton's *Principia Mathematica*, the British physicist formulated a notion of time that fits with our everyday experiences. He pictured a universal stopwatch whose ticks beat out the steady passage of seconds, minutes and hours across the cosmos. No matter where you are or how you are moving, in Newton's view, you would agree that Ellis takes exactly 10 minutes to sip his coffee on a bench in a leafy quadrangle of Trinity College before placing his cup down beside him. Every 15 minutes, he hears the bell of Trinity's ornate clock tower — set in place half a century before the young Newton ever set foot on college grounds — punctuating the forward march of time.

For a time, Ellis put cosmology on hold to help tackle housing problems in his native South Africa where, under apartheid, millions of non-whites were forced to live in squalor.

Ellis' own march began in Johannesburg in 1939, when he was born to an English immigrant father. The family moved to Cape Town after Ellis turned 12, and he was placed in a boarding school. There he became fascinated with tinkering with model trains, breaking them apart and then putting them back together to learn how they worked.

But what might have been idyllic formative years were tainted by the 1948 institutionalization of apartheid, a set of laws that enforced white supremacist rule over those categorized as "blacks," "coloreds" and "Asians." As a white South African, Ellis admits, "it would have been easy to be totally isolated from this," were it not for his parents. Both were vocal opponents to the regime, using the newspaper his father edited to criticize the government's racism.

As an undergraduate, Ellis studied architecture for a year and then switched to physics and math. He laughs that while he "did not have the imagination to come up with designs for buildings," he was attracted to discovering the

George Ellis says Einstein went too far — the future is not set.

blueprints of the larger universe. Like all physics students in the 1960s, he learned that these blueprints mostly had been laid out by Einstein. That's when time started getting complicated for Ellis.

ON THE BLOCK

In 1905, Einstein overturned Newton's harmonious picture of a standard universal time. He replaced it with a discordant, relative view in which different people could disagree about the duration of events, and even the order in which they happened. The young Einstein came to the remarkable realization that time was, in fact, a fourth dimension, alongside the three dimensions of space that we see around us, creating what has become known as the "block universe" picture of reality.

To explain what a block universe looks like, imagine taking successive photographs of a location, says Ellis, such as a series of snapshots of anxious Cambridge students hurrying across the Trinity quadrangle, books in hands, on their way to exams. If you projected the photos one after another, you would make a movie through which time appeared to pass, corresponding to our intuitive view of time's flow. But if you

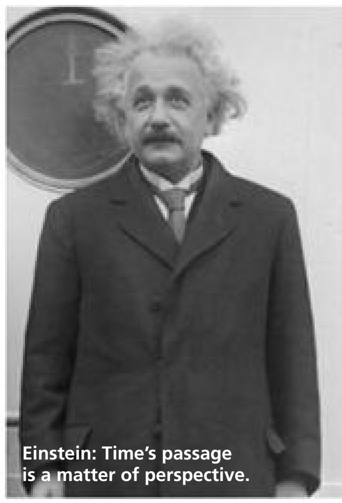
Einstein replaced Newton's standard universal time with a discordant, relative view in which different people would disagree about the duration of events, and even the order in which they happened.

stack the images on top of each other, you would see the students' entire journeys across the quadrangle mapped out in front of you, all at once. The second example is similar to the block universe view, where past, present and future all coexist simultaneously, and the passage of time has no meaning; all events coexist side by side.

Of course, a set of photographs captures only two dimensions of space mapped out along the time dimension. Extend this to three spatial dimensions and across the whole cosmos, encompassing both its entire history and all future events yet to come, and you have Einstein's four-dimensional block universe — a static record that spans all that ever has happened, and all that ever will happen.

What's most disarming about the block universe, remarks Ellis, is that unlike a movie that plays through a series of successive instants, there is no special point in time that all inhabitants would agree on as "now" — no unique marker that separates the fixed past from the open future. Just as two students seated in different corners of the quadrangle may disagree over the length of the shadow cast by the Trinity College clock tower, based on their perspective, so might it be with time: Einstein realized that since time is just another dimension in the block universe, then depending on where two people are in space-time, they could also disagree on the duration of events. Some would, completely accurately, argue that it took Ellis longer than 10 minutes to drink his coffee.

Newton: Time is standard across the universe.



Einstein: Time's passage is a matter of perspective.

There's more. Just as the students would disagree on whether the clock tower was to Ellis' right or left, depending on where they stood, two people in Einstein's block universe could even argue over the order in which events occurred. To one person, the Trinity clock might strike 2 p.m. before Ellis finished his last sip, and to another, the bell chimed only after he was done. These discrepancies are based purely on the speed and direction the people are traveling in the block universe, because this affects the time it takes light from those events to reach them. These

time differences are imperceptible at human speeds, but they have been verified in experiments involving the International Space Station as well as extra-fast airplanes.

In the block universe, then, what someone perceives as the future is what someone else saw as the past, depending on the person's position and motion. Events that have yet to happen for one person, it appears, have already happened for another. The future, though it remains unknown to you, seems to be written already. Einstein himself described it thus: "People like us, who believe in physics, know that the distinction between past, present and future is only a stubbornly persistent illusion."

Most physicists have learned to accept that the direction of time chosen as "forward" is arbitrary in Einstein's conception of the universe and the fundamental equations governing our cosmos, but Ellis' gut told him to look deeper. "This is where I come back to trying to have a realistic feel for things," he says.

TIME OFF FROM TIME

Even though Ellis had reservations about time and the block universe, he still admired Einstein, and his respect deepened when he moved to Cambridge in 1960 to pursue a doctorate degree with world-renowned cosmologist Dennis Sciama. During his early years as a researcher, Ellis earned a reputation as a world-class cosmologist for his ability to tackle the tricky mathematics needed to fully solve some of Einstein's space-time equations.

Ellis respected Einstein's mathematical ingenuity, but he later balked at the philosophical implications of the block universe, in which the future stands on the same footing as the past. "If we are just machines living out a future that has already been set, then Adolf Hitler had no choice to do other than what he did; Hendrik Verwoerd, the architect of apartheid, had no choice," Ellis says. It would be meaningless to tell them they were doing something wrong, he adds. "To me, that's an untenable view of the world that will lead to great evil because people will just stand by as evil takes place."

At Cambridge, Ellis soon worked with the young Stephen Hawking, a fellow student of Sciama's. But while Hawking went on to gain international fame for his work on the origins of the universe and the nature of black holes, Ellis did not share in those glories. In 1973, at age 33, he left Cambridge, breaking off his close research relationship with Hawking, and returned to South Africa to set up his own team within the mathematics department at the University of Cape Town. It may have been a backward step for his cosmology research, but the area's draw was irresistible — partly because he missed friends and family, but mainly because he felt a duty to try to help remedy the injustices in his homeland. "I wanted to see if I could make a difference," he says softly.

There was, of course, no easy fix for South Africa's ills, but Ellis turned his skills to providing help where he could. Placing his cosmology research on hold, he developed mathematical models to help tackle the housing problems

"The past is real and can have had an effect on us today, but the future cannot influence us because it does not yet exist."
–George Ellis

Future Imperfect

What better place to ponder time's flow than the centuries-old Trinity College at the University of Cambridge? While Einstein would suggest the future is just as real as the past, Ellis posits that the future remains a collection of possibilities until it merges into the present.

PHOTO ILLUSTRATION BY DAN BISHOP/DISCOVER; HISTORICAL PICTURE ARCHIVE/CORBIS; ALAN COPSON/JAI/CORBIS

that had left millions of non-whites squatting in wretched conditions. His research culminated in two books, which he co-authored, severely criticizing the government's policies. His writing was brought before the South African Senate, where the minister of housing denounced Ellis and his aims as "pernicious." But within the decade, the government accepted the policy changes that Ellis had proposed. Apartheid eventually ended in 1994, a year that also saw the election of Nelson Mandela as president.

Convincing policymakers that his housing project was necessary reinforced Ellis' view that mathematics and science should be harnessed to make the world a better place. "I got involved in these various projects on the ground, where we were actually trying to make a difference," he says. Unlike his early work on esoteric physics, he adds with a laugh, "it gave me a feeling for how mathematical modeling relates to the real world."

During these years, Ellis also worked on cosmology, though not as vigorously as he would have liked because of the more immediate needs in his country. Now he had a chance to return to it, but his work in the "real world" inspired him to tackle the structure of the universe from a more philosophical angle.

CHOPPING THE BLOCK UNIVERSE

With the twilight of his career approaching, Ellis switched his focus in 2005 back to the more esoteric gripes with fundamental physics that vexed him as a student: how to deal with the absence of personal accountability in a conception of reality without time. To this end, he revisited Einstein's

> “Quantum collapse is happening all the time, everywhere. Every time a particle of light hits a leaf, quantum uncertainty about that particle changes to certainty.”
>
> –George Ellis

block universe with an eye toward developing a new model that keeps the best features — including experimentally confirmed predictions about how time is relative — while reinstating the notion that the present is fundamentally distinct from the past and the future.

Ellis’ new model is a modification, rather than a radical upheaval, of the block universe. In his framework, set out in a series of highly regarded papers published from 2006 onward, Ellis retains four-dimensional space-time, in line with relativity’s predictions. However, he argues that Einstein took that concept too far. There’s no need to assume that the fourth dimension must already exist out into infinity. Thus Ellis’ model has one crucial difference from Einstein’s: The future boundary does not encompass all that will ever happen.

Instead, the leading edge of space-time marks the “present” crawling outward, moment by moment, transforming tomorrow’s maybes into yesterday’s fixed happenings. “Tomorrow there will be one more day in the universe than there was today,” says Ellis. “The past is real and can have had an effect on us today, but the future cannot influence us because it does not yet exist.”

Ellis’ calculations show that the evolving block universe does not contradict relativity’s prediction that two people can disagree on the order of two events. In both Einstein’s and Ellis’ pictures, the time at which each person perceives both events to have occurred is based on the discrepancies between how long it takes light from each event to reach them. In Einstein’s view, these events — and all future events — coexist. But in Ellis’ picture, both events must lie in the portion of the evolving block that houses the past; they are fixed into reality before information about them reaches anyone. Similarly, in Ellis’ view, two observers can disagree on the duration of an event, but only if that event has already crystallized into the past. Thus, Ellis’ model of time retains enough of the block universe to match with relativity’s predictions, but without needing to take Einstein’s drastic last step of assuming that the fourth dimension is solidified into the infinite future.

If Ellis is correct, how does he explain the mechanism that causes the front edge of the universe to push forward? “The surface is where the uncertainty of the future changes to the certainty of the past,” says Ellis. He found hope in another branch of physics, well known to physicists, where a transformation from uncertain possibilities observably becomes a fixed reality. It’s in the realm of quantum mechanics — a weird theory that governs the behavior of subatomic particles.

At the quantum level, chance and probability rule. For instance, it is impossible to predict the precise state of a particle — its position and energy — until you measure it. Before that moment, the particle comprises myriad possibilities, a “superposition” of all possible locations, speeds and energies at once. Upon being observed, however, this bubble bursts, and the particle collapses into a single, randomly determined identity. This is a strictly one-way process: Once collapsed, the particle can’t spontaneously revert to its multiple personalities. And there is no way to predict which state the particle will settle into; this final outcome is not predetermined.

This apparent contradiction of Einstein’s block universe has been demonstrated many times in the lab. Physicists have known for decades that quantum mechanics and general relativity are incompatible. Their contrasting notions of the nature of time — in one case as a real flowing entity and in the other as an apparent illusion — is one of the major hurdles in uniting the two frameworks into a single theory of quantum gravity that explains the motions of all objects, from atoms to planets.

Quantum experiments give Ellis the heart to believe that time is real and Einstein’s simple block universe is wrong. “Some physicists say that the future is already written into today, but I think that they are not taking quantum uncertainty seriously,” says Ellis. “Quantum uncertainty, to me, says the future is not determined until it’s happened.”

He contends that at the front edge of his evolving block universe, the uncertain future crystallizes into the past through a sequence of microscopic quantum events. At each event, particles are forced to transform from their original uncertain quantum state — where they juggle multiple conflicting identities — and settle into one rigid identity. As adjacent particles go through this process, a wave of certainty converts the open future to the closed past.

NOT SO FAST

Ellis may have worked out a framework that puts time back into physics, but he’s still a long way from convincing his peers. Julian Barbour, a visiting professor at the University of Oxford, respects Ellis, but he has long held the view that time is “excess ontological baggage” that should be thrown out of physics entirely. Just because something feels natural,

AGSANDREW/SHUTTERSTOCK

he notes, it does not necessarily mean that it is the correct description of reality.

"This reminds me of Galileo trying to persuade the Aristotelians that the Earth moves around the sun," says Barbour. Although this belied the everyday experience of a solid and stationary planet beneath our feet, it was ultimately right. The notion that we move through time, Barbour believes, will one day be recognized as archaic a concept as the belief that the sun revolves around the Earth.

Craig Callender, a philosopher of physics at the University of California, San Diego, sympathizes more with Ellis' frustration: "Physicists often pooh-pooh our experiences of time, saying that it's just an illusion, that it's rubbish. But if it is an illusion, then it's a very persuasive one." The evolving block universe may be correct, Callender says, but before Ellis can convince most of his peers, he will need to give a more rigorous explanation of how quantum processes, which usually affect only subatomic objects in experiments, cascade upward to create an effect across the cosmos.

Another objection is that vast swaths of the universe are devoid of people to observe quantum processes, which physicists traditionally say is what triggers particles to transform from their uncertain superpositions into defined states. So who or what is observing these quantum particles and forcing them to change their nature? Ellis counters that quantum collapse can occur without a conscious observer, whenever particles collide with each other, knocking each other out of their uncertain states. This idea, called decoherence, is already gaining popularity (independently) among physicists.

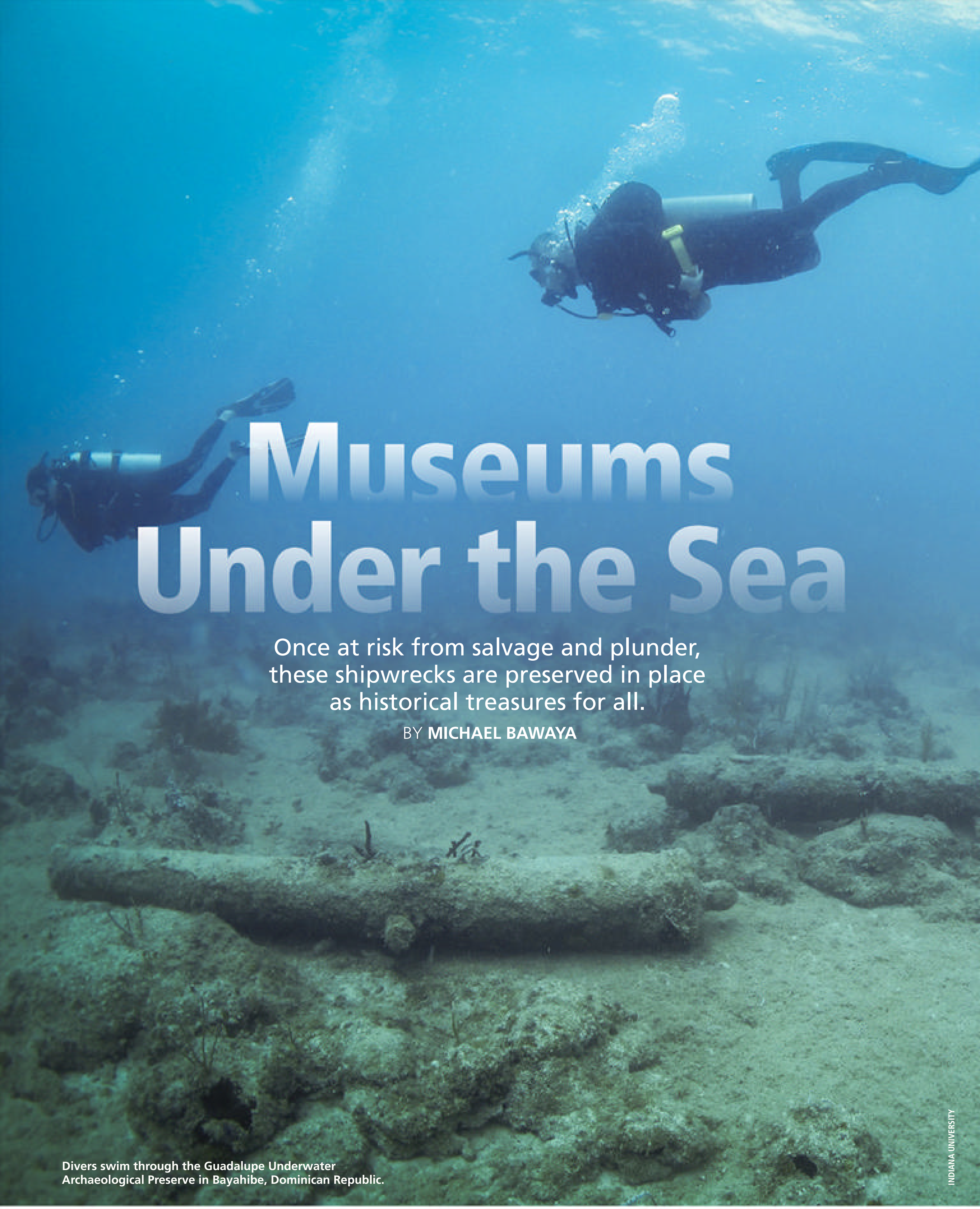
"In my opinion, quantum collapse is happening all the time, everywhere," Ellis says. Pointing to a sun-drenched tree, he adds: "Every time a particle of light hits a leaf, quantum uncertainty about that particle changes to certainty."

Still, Ellis concedes that his ideas are speculative. "I wouldn't say I think it's all tied together yet," he admits. "But I think that I've got a framework in which everything makes sense."

And he scoffs that the burden of proof should lie not with him, but with those who claim that time is a mirage of our own making. After all, Ellis says, not only does his model gel with quantum experiments that appear to show that time is real, it also encapsulates our common sensations, "which is tested every day, by everyone, whenever anything happens." Life itself is an experiment that backs his view.

With this in mind, he quotes from the ancient Persian poet Omar Khayyam's musings on the visceral difference between what has gone and what is yet to come: "The moving finger writes; and having writ, moves on: Nor all thy piety nor wit shall lure it back to cancel half a line, nor all thy tears wash out a word of it." Then, with a guttural laugh, Ellis throws down a challenge to his critics: "If you don't believe that, then you go back and change the past!" D

Zeeya Merali**, a London-based writer and blogger for* **www.fqxi.org/community, covers physics for* Discover *and other magazines.*



Museums Under the Sea

Once at risk from salvage and plunder, these shipwrecks are preserved in place as historical treasures for all.

BY **MICHAEL BAWAYA**

Divers swim through the Guadalupe Underwater Archaeological Preserve in Bayahibe, Dominican Republic.

INDIANA UNIVERSITY

People who value historic shipwrecks have often wanted to raise them for preservation and display in museums. Charlie Beeker has a better idea: bring the museum to the wreck.

Beeker, director of Indiana University's Office of Underwater Science in Bloomington, started diving in 1963, a time when historic shipwrecks had no value beyond exploration and salvage. The dive magazines of that time, replete with tales of treasure hunting, glamorized the looting of shipwrecks. When Beeker took a diving instructor course in Key Largo, Fla., in the 1970s, divers had damaged most of the Florida Keys' historic wrecks. Artifacts such as cannons and anchors became ornaments at marinas, hotels and restaurants along U.S. Highway 1.

Preservationists called for changes and began to float the concept of underwater museums as a way to protect wrecks and keep artifacts in place, but the idea didn't gain real traction until the passage of the Abandoned Shipwreck Act in 1988. Beeker was on the committee that helped draft the legislation, which acknowledged the value of historic wrecks and clarified the ownership and management of them on federal, state and tribal submerged lands.

The following year, Beeker helped establish the San Pedro Underwater Archaeological Preserve in Florida, and he went on to play a role in creating 11 more underwater parks in Florida and California. By 2009, a national system of marine protected areas was established under the auspices of the National Oceanic and Atmospheric Administration to preserve the shipwrecks, elevating them from plunder to historical treasures.

But that failed to deter some treasure hunters, who simply moved to the Caribbean, where the pickings are easy and plentiful. For instance, in the Dominican Republic, treasure hunters

are allowed to plunder wrecks so long as they split the take with the government. So Beeker began to focus his efforts there as well.

Since 2008, Beeker and his colleagues have been collaborating with the government's ministries of environment, culture and tourism and the U.S. Agency for International Development. Together they have established living museums of the sea, such as the Guadalupe Underwater Archaeological Preserve and the 1699 Captain Kidd Living Museum of the Sea, with several more in the works. The Captain Kidd shipwreck contains in situ archaeological material, while the others comprise artifacts that were raised from the sea in the past and subsequently returned there.

The museums feature mooring buoys for boats, historic-marker buoys and underwater plaques with interpretative information. Visitors are admonished to "take only photos, leave only bubbles." The museums increase cultural heritage tourism, which, in turn, stimulates economic development, providing the Dominican Republic with a sustainable alternative to treasure hunting.

Beeker takes an expansive approach to shipwreck preservation. "We're making an archaeological project an environmental project," he says. "We have a holistic view of the resource." That view entails preserving the ecosystem around the wreck as well as the wreck itself. Large artifacts, such as cannons and anchors, provide hard substrate and rugosity that create an ideal habitat for corals, fish and other biota.

Beeker's success in the Dominican Republic hasn't come easily, and he acknowledges there are plenty of people who want him to fail. Treasure hunters have sued him — one even confronted him in a bar. (Beer bottles were flung, and police were called.) Local fishermen complain that the underwater museums interfere with their business. Working with foreign governments can also be difficult, particularly those easily seduced by the promise of treasure hunters' booty. But Beeker is quick to remind them, "You can only sell it once as a treasure hunt. I can sell it forever as a park." And what parks they are.

Guadalupe Underwater Archaeological Preserve

In 1976, the Dominican Republic's Underwater Archaeological Recovery Commission began excavating the *Nuestra Señora de Guadalupe*, a Spanish galleon designed to carry quicksilver (mercury) that was used in Spain's gold and silver mines in Mexico.

Carrying a load of quicksilver and 600 people, she set sail in 1724 from Cádiz, Spain, to Veracruz, Mexico. The *Guadalupe* ran aground and sank in a reef off the coast of the Dominican Republic during a storm. More than half the passengers made it to shore.

Salvors recovered many of the *Guadalupe*'s artifacts, the most important of which were conserved and exhibited in several museums in Santo Domingo. But the majority of the artifacts were either kept in storage or were not conserved because of a lack of resources. In 2002, Indiana University suggested using some of the latter artifacts, including several cannons, in an underwater museum exhibit that opened that summer.

Located in front of the Viva Dominicus Beach Resort in Bayahibe, the artifacts in the Guadalupe Underwater Archaeological preserve sit at a depth of about 26 feet near a coral reef. The museum is an appealing site for divers, who can see authentic artifacts from a historic shipwreck, and the resort uses it to attract business.

Indiana University students monitor biological growth on an anchor ring.

COURTNEY MICHALIK

Quedagh Merchant

The Captain Kidd Shipwreck Living Museum of the Sea's dedication took place May 23, 2011, the 310th anniversary of the infamous Kidd's hanging in London for crimes of piracy. The museum rests in less than 10 feet of water just off the shore of Catalina Island in the Dominican Republic.

Kidd, although sanctioned by England as a privateer, was accused of piracy after he captured the *Quedagh Merchant* (also known as the *Cara Merchant*) in the Indian Ocean in 1698. He abandoned the vessel, which he had renamed the *Adventure Prize*, off the southeast coast of the Dominican Republic. For more than three centuries, it escaped the notice of the many people who searched for it until, in 2007, a snorkeler came upon a pile of concreted cast-iron cannons.

Dominican Republic officials contacted Beeker, who happened to be on the north coast searching for a Columbus shipwreck. (Beeker made the news in May 2014 for analyzing artifacts suspected at the time to have come from Columbus' *Santa Maria*.) Beeker and his Indiana University colleagues received international media coverage when they confirmed the Kidd wreck in 2007. Beeker and his team discovered 26 guns, three anchor crowns and part of the lower hull, among other artifacts.

Like all living museums in the sea, the Kidd shipwreck protects biological resources — most notably, relatively large populations of elkhorn and staghorn coral — as well as archaeological resources.

Charlie Beeker, pictured at top in the red dive suit, and two visiting divers inspect a cannon from the Kidd shipwreck. Researchers in the middle photo work to preserve the ecology formed around such wrecks. A beach monument at left honors the living museums of the sea.

FROM TOP: INDIANA UNIVERSITY; COURTNEY MICHALIK; CHARLIE BEEKER/INDIANA UNIVERSITY

Nuestra Señora de Begoña

Historical accounts have it that in 1725, the Spanish frigate *Nuestra Señora de Begoña* encountered a violent storm while en route from Venezuela to the Canary Islands. The *Begoña* — carrying cacao, dyewood, contraband coins and other treasure — diverted to Santo Domingo, where the captain grounded the sinking ship near shore.

In 2010 the Dominican Republic awarded a permit to Beeker and his crew to excavate at a small beach at La Caleta Underwater National Park, where, several hundred feet offshore, they believe remnants of the wreck lie.

Excavating an area closer to the shore, they found many artifacts that likely came from the *Begoña,* including a cast-iron cannon, a brass wine spigot and examples of contraband precious metals.

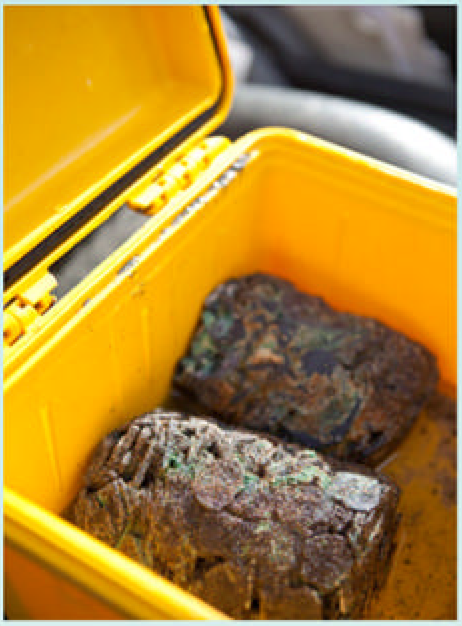
The artifacts were extremely fragile and in need of timely conservation. When exposed to air, items made of organic materials such as wood, leather and textiles can quickly degrade. Metal artifacts quickly corrode.

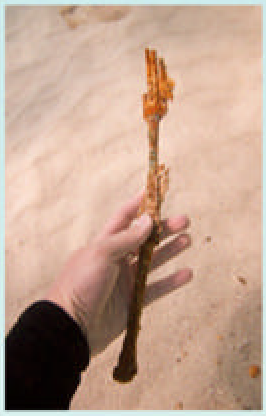
The artifacts are often encased in concretions, which form when sand grains, shell particles, coral and marine plants adhere to submerged articles. During excavations, the archaeologists found Spanish silver coins concreted into the shapes of the sacks that once contained them and recovered a cup attached to a large, unidentified concretion weighing about 100 pounds.

Since 2010, Indiana University, in collaboration with other organizations, has been working to turn the *Begoña* wreck site into a living museum of the sea. D

***Begoña* artifacts, below, have washed up at La Caleta, a popular public beach near Santo Domingo, pictured at top. Researchers often contend with amateurs searching the shallows at the beach. Above, archaeologist John Foster uses a suction dredge and Peace Corps scientific diver Lydia Barbash-Riley uses a proton magnetometer.**

COURTNEY MICHALIK (9)





Top: Researchers hold a conglomerate of silver platters and candlesticks recovered from the *Begoña*. Clockwise from bottom left: Other artifacts from the shipwreck include a cast-iron muzzle-loading cannon, a concreted silver platter, silver coins concreted in the shape of the bags that held them, and plates and flatware from the remnant wooden base of a chest.

***Michael Bawaya** is the editor of* American Archaeology *magazine. He also writes for* Science, Nature, New Scientist *and others.*

DEATH IN THE LAB

A UCLA laboratory fire took Sheri Sangji's life. Her boss and the university closed ranks. Will her family's crusade for justice make researchers any safer?

BY **BERYL LIEFF BENDERLY**

ILLUSTRATIONS BY **JONATHAN BARTLETT**

WITH THE CAMPUS NEARLY deserted for winter break, this Monday in late 2008 should have been a quiet one at the University of California, Los Angeles. Around 1 p.m. Dec. 29, Sheharbano "Sheri" Sangji began an experiment in the fourth-floor chemistry lab where the 23-year-old worked as a research assistant to chemistry professor Patrick Harran.

Alone at the bench, wearing a synthetic-fiber sweatshirt, she put on goggles and gloves and began the procedure Harran had outlined to her that morning as part of work to develop a drug to treat obesity. It included transferring a liquid called tert-butyllithium from the bottle it came in to another bottle.

Tert-butyllithium is pyrophoric — it ignites on contact with air — so its manufacturer, Sigma-Aldrich, sent detailed instructions for safe handling with each bottle. Only "fully qualified and experienced laboratory workers" should work with it, the instructions say, according to an investigative report. They should receive training on the specific procedures needed to stay safe: goggles and gloves, but also a fire-resistant lab coat over natural-fiber clothing down to the underwear, and possibly a full-face respirator mask. If a syringe is used, it should be glass, at least twice as large as the quantity to be transferred and fitted with a needle a foot or two long. Sangji had learned to make a transfer from one of Harran's postdoctoral researchers, who would later admit he hadn't read those instructions and didn't follow them.

Tert-butyllithium is a pyrophoric chemical compound — it ignites on contact with air.

Sangji hoped to spend the holiday break with her sister and brother, but she couldn't get time off from the job, which she started just nine weeks earlier. She considered the job an interesting way to spend the year between her college graduation the previous May and law school the coming September, using her Pomona College chemistry degree to earn money for law school.

In the lab that December day, Sangji relied on what she had learned from the postdoc researcher, inserting the 2½-inch needle of a large plastic syringe into the bottle's seal. Suddenly, the syringe came apart in her hands, spilling the liquid, which instantly ignited, setting her sweatshirt ablaze. Screaming in pain and panic, she ran for the door — and away from the emergency shower just feet from her that was meant for precisely this type of situation.

Weifeng Chen, a postdoc working elsewhere in the lab, raced over. Tearing off his lab coat, he frantically used it to try to smother the fire engulfing Sangji. When it, too, began to burn, he tried water from a sink. Meanwhile, postdoc Hui Ding dashed in, then ran to call 911 and summon Harran from the floor above. Only when emergency responders arrived did anybody drench Sangji under the shower. No one in the lab was drilled on what to do in case of fire.

The fire would ignite a landmark legal case and the first-ever felony charges for safety violations against an American professor. In legal filings and comments on the case, UCLA officials would consistently call the fire "a tragic accident." Laboratory safety experts, however, say the fire was no more an accident — in the sense of a mishap that happens by chance — than being thrown from a car while not wearing a seat belt.

No one knows how many chemical safety incidents occur in university laboratories each year. The U.S. Chemical Safety Board, a federal agency that investigates chemical safety events, has "preliminary" information on more than 120 incidents since 2001. Workers in university labs — including 110,000 graduate students and postdoctoral researchers, plus uncounted undergraduates and technicians — are 11 times more likely to get hurt in a university lab than in an industrial lab, according to U.S. Occupational Safety and Health Administration statistics.

A SISTER IN ANGUISH

Naveen Sangji, Sheri's 26-year-old sister, arrived in Los Angeles the next morning on the first plane she could get from Boston, where she was in her fourth year at Harvard Medical School.

Slender and petite, Naveen appears too slight to contain the passion that burns in her large, dark eyes when she speaks of the "promising, brilliant young woman with her whole life ahead of her" — the idealist, the student, the soccer player, the devoted friend. "Words cannot express her spirit," she says. In the intensive care unit of the Grossman Burn Center that day, Naveen felt her trained clinical detachment fail her. The sight of her kid sister's face — unblemished by the fire, peeking out among the thick bandages shrouding her ears, neck, chest, arms, hands, back and thighs — engulfed Naveen in anguish. The slightest touch to Sheri's skin caused her to scream in agony.

Sheri had third-degree burns over 40 percent of her body. Naveen, who hoped to be a burn surgeon, knew the best possible outcome was months in the ICU, extreme pain, numerous surgeries and years struggling to recover function.

An uncle also reached the burn center that morning from Toronto, where the extended family had moved from their native Pakistan when Sheri was a teenager and Naveen was in her early 20s. Their parents, who were traveling in Asia, reached Sheri's side three days later.

Amid Naveen's terror, grief and "utter helplessness," however, her scientific mind demanded to know how this happened. According to Naveen, Harran came to the burn center on Dec. 31. She had spoken with him on the phone from Boston. Now she and her uncle met with him. Harran told them Sheri was very conscientious in the lab and he described the transfer, Naveen recalls. The uncle, a structural engineer whose work involved fire safety, was the first to frame the question that would haunt Naveen and form the crux of the legal struggle. "After Harran finished his spiel, my uncle asked him why wasn't she given fire-retardant gear," Naveen says.

"Harran said they used lab coats 90 percent of the time," she says. "I remember that because I wrote it down." The investigative report would find that, "with few exceptions, personnel did not

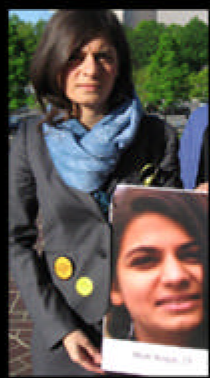
DAVIDE AUFIERO

routinely wear lab coats while working in the lab."

Over the following weeks, Naveen and her parents watched Sheri endure multiple surgeries. Between operations, encased in bandages and tubes, she spent her waning strength with those she loved, who read her the many messages arriving from friends and family around the world.

Meanwhile, Naveen began seeking the answer to her uncle's question. "Sheri suffered agonizing injuries," she says; she expected that some official body would conduct a full and impartial investigation. But meetings with UCLA officials — including the university fire marshal, the chemistry department chair and Chancellor Gene Block — produced no new information. As Naveen's search widened, Sheri's burns deepened, and her organs began to fail. On Jan. 16, 2009, Sheri died.

Sheri's death, and the way she died, left her parents — a Montessori teacher and a small-business man — "mere shadows of the people they used to be," Naveen says. She knew she would have to lead the drive for answers. Justice for Sheri, the family agreed, meant not revenge or material damages, but rather a public trial that laid out the truth and held accountable those who should have protected Sheri. The only thing her parents want, Naveen says, is that "someone else's child shouldn't have to suffer, other parents shouldn't have to suffer."



Naveen Sangji, with a photo of her sister Sheri, has pushed for better protection of university lab workers.

As Sheri lay dying and Naveen pursued answers, both Harran and UCLA — the fifth-largest employer in Los Angeles and one of the world's top-rated universities — began taking refuge in the same argument, one they would carry into the upcoming legal fight. Sheri, they maintained, was "an experienced and skilled chemist," though the chemical company where she worked for several months before UCLA considered her a novice researcher who needed supervision. "The campus continues to believe that she was using an appropriate method," Vice Chancellor for Legal Affairs Kevin Reed said in a statement in June 2009. The university, Block would repeatedly say, stood with Harran.

A STELLAR RISE

Harran and close associates refused or did not respond to interview requests for this story, but his remarkable research life is a matter of public record.

Harran's career as a scientific star began early, with honors at Skidmore College, Ph.D. studies at Yale and two postdoctoral years at Stanford. In 1997, at the strikingly young age of 28, he landed his first faculty job in a competitive labor market as an assistant professor at the University of Texas Southwestern Medical Center in Dallas. He advanced with exceptional speed.

He beat out a dozen other labs in a race to synthesize a toxin that attacks cancer cells. Nearly alone among anti-cancer agents, diazonamide A did not harm normal cells, suggesting the possibility of a drug with few side effects. In 2001, Harran's tour de force research also uncovered and corrected an error in the initially published chemical structure. He also showed that diazonamide A could kill cancer cells by a method previously unknown, making him not only a master of chemical synthesis but a contributor to cancer research.

He gained tenure in five years and full professorship in just seven — a time when most academics are first up for tenure. Less than a year later, he had an endowed chair in biochemistry.

Beyond technical mastery, Harran reportedly finds aesthetic and humanitarian value in crafting molecules. "Synthetic chemistry is like painting or architecture," he told the Glens Falls *Post-Star*, published near his childhood home of Corinth, N.Y. "We have almost infinite possibilities in the ways we can create new materials. … Discovering a new type of reaction or finding something out about a molecule that, for example, could be very useful, or could change people's lives? That's remarkable."

In July 2008, Harran moved to UCLA, and the university provided $3.2 million to get his new research operation underway. Naveen said Sheri told her that Harran pushed his staff to help him win "the Nobel Prize in six years."

SAFETY STANDARDS ON TRIAL

State investigators soon began seeking answers. As a university employee, Sheri came under the jurisdiction of the California Division of Occupational Safety and Health, known as Cal/OSHA. Had she been a student, the agency would have lacked jurisdiction because occupational safety laws cover only paid workers. No government agency had the power to exact penalties, for example, when a lab explosion in 2010 critically injured Texas Tech University graduate student Preston Brown or when a lathe strangled Yale University senior Michele Dufault in 2011 in a university science building.

Sheri's case would be different. In May 2009, Cal/OSHA fined the University of California $31,875 on four violations of the occupational safety law: lack of required safety training, lack of needed protective equipment, failure to maintain an "effective Injury and Illness Prevention Program" and lack of required training records. It classified the first three violations as "serious," indicating a likelihood of serious injury or death.

These findings and fines were hardly the inquiry that Naveen had expected. The family wanted "a full investigation and want to see a more comprehensive questioning into how my 23-year-old sister lost her life from injuries sustained while working at UCLA," she says. In the *Journal of Chemical Safety*, lab safety expert Neil Langerman wrote, "The death of Ms. Sangji was the direct result of management failure throughout the UCLA administration, from Chancellor Gene Block through Professor Harran and the [Environmental Health and Safety] department." Later developments would confirm this view.

Much of the academic scientific community, however, agreed with UCLA and, amid expressions of shock and sorrow, argued that Harran had done nothing that lab chiefs across the country do not do every day.

Scientists in industry took a different view. Officials at three major chemical companies published an open letter citing lax

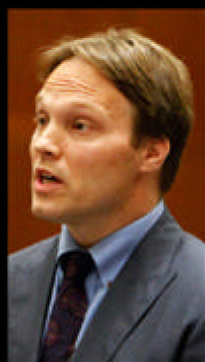
LIZ BORKOWSKI, MPH


POLICE LINE DO NOT CROSS

university safety standards that require companies to provide new hires arriving from campuses "weeks of remedial safety training before [they] are allowed to work in their labs." William Banholzer, then technology chief at Dow Chemical, says in industry, "If you can't do the work safely, you can't do it in our company. … If somebody violates our safety protocols, we'll dismiss them. I'll go into a lab and shut them down."

Determined to force the authorities to seek deeper causes, the family appealed the Cal/OSHA citations and pressed for the opportunity to express their concerns to the agency, as did Sheri's labor union, the University Professional & Technical Employees Local 9119 of the Communications Workers of America. UCLA, which initially paid the fines, also filed an appeal of the findings.

Cal/OSHA authorized a new investigation. Senior Special Investigator Brian Baudendistel interviewed Harran, as well as the postdoc who was said to have demonstrated the transfer to Sheri, the two postdocs who tried to help her and her boss at Norac Pharma, where she worked before UCLA. Baudendistel's 95-page report, released in December 2009, detailed how, more than two months before the fire, a university safety inspection noted inadequate use of lab coats and other protective equipment in Harran's lab and ordered improvement within 30 days, a requirement Harran failed to fulfill.



UCLA professor Patrick Harran faced felony charges after violating safety rules.

AL SEIB/LOS ANGELES TIMES

"Dr. Harran," Baudendistel wrote in his report's conclusion, "simply disregarded the open and obvious dangers presented in this case and permitted victim Sangji to work in a manner that knowingly caused her to be exposed to a serious and foreseeable risk of serious injury or death." He sent the report to the district attorney, recommending a charge of involuntary manslaughter.

By now a surgical resident in Boston, Naveen feared that the DA would not prosecute so powerful an institution and its prominent faculty member. In all the time she could spare, she worked to bring pressure on the DA and keep the case alive in the media. She made calls, wrote letters and collected thousands of signatures urging prosecution. "There is no doubt in our minds," Naveen wrote to the DA just days before the statute of limitations expired in late 2011, "that criminal prosecution, against the university and the professor, will be the single most effective deterrent to unsafe laboratory conditions in the future at UCLA, and at other universities."

In December 2011, the Los Angeles DA charged Harran and the regents of the University of California with three felony counts, later raised to four, of willful violations of California's labor code with a resultant death. Conviction on all counts carried up to four-and-a-half years in prison.

Chancellor Block denounced the charges as "unwarranted" and again pledged UCLA's "full support," including legal defense. Some scientists objected to Harran being "railroaded" for conduct most considered ordinary. Others, especially lab safety experts, saw conviction as the well-deserved — and cautionary — consequence of neglect.

In July 2012, the university regents settled with the DA. They agreed to "accept responsibility for the conditions under which the laboratory was operated," to create a law school scholarship in Sheri's name and to establish, in all the chemistry labs on all of the system's 10 campuses, an extensive program of required safety training and compliance for all lab workers. In exchange, the DA dropped the felony charges.

Never before had an academic institution come under a legal standard equivalent to that found in industry, where management enforces safety from the top down.

Harran, however, did not settle and continued to maintain his innocence. Given the high risk of conviction should a jury hear Baudendistel's conclusions, his defense team used every possible means to prevent a trial. They made repeated motions to dismiss the charges, knowing that the statute of limitations precluded the prosecution ever bringing them a second time. Delays postponed arraignment dates. On Sept. 5, 2012, over the defense's objections, a Los Angeles judge entered four not-guilty pleas for Harran. That November, a judge ordered him to stand trial.

Harran's lawyers eventually petitioned the California appeals court to dismiss the charges because the university, not Harran, was Sheri's employer. The appeals court asked for briefs, raising the possibility of a dismissal, but it never heard arguments. In May 2014, the district attorney settled with Harran.

Harran would accept "responsibility for the conditions under which the laboratory was operated" but would not plead guilty. The district attorney will dismiss the charges if, during five years of probation, Harran teaches summer courses in chemistry to disadvantaged high school graduates, lectures incoming UCLA chemistry students about lab safety, performs 800 hours of service in the UCLA hospital and donates $10,000 to the burn center where Sheri died. Because the settlement allowed Harran to avoid criminal penalties, the landmark case that many had hoped would set a new standard for accountability in labs across the country ended without settling the legal question of whether the lab chief has personal responsibility for the safety of students and workers.

In the courtroom on the last day of proceedings, after nearly six years of anguish and effort, Naveen rose to tell the judge of Sheri's dauntless spirit and ruined future, of her sister's agony and her family's desolation. With many of her listeners in tears, Naveen called the settlement "barely a slap on the wrist for the responsible individual. … We do not understand how this man is allowed to continue running a laboratory, and supervising students and researchers. We can only hope that other young individuals are better protected in the future."

The agreement, one of Harran's lawyers told reporters outside the court, will "allow professor Harran to continue with his life-saving work."

Harran said nothing as he left the court.

UCLA spent nearly $4.5 million on his defense. D

__Beryl Lieff Benderly__ covers science policy for Science Careers *and contributes to other publications. She is based in Washington, D.C.*

LEEUWENHOEK'S LUCKY BREAK

HOW A DUTCH FABRIC-MAKER BECAME THE FATHER OF MICROBIOLOGY.

BY **PAUL FALKOWSKI**

ILLUSTRATION BY **BLUE LANTERN STUDIO/CORBIS**

Although his microscopes weren't much bigger than a modern microscope slide, Anton van Leeuwenhoek (above) coaxed 200x magnification out of his small devices.

PERHAPS ONE OF THE BIGGEST IRONIES IN BIOLOGY IS THAT microbes, which are the oldest self-replicating organisms on Earth, were among the last to be discovered and have largely been ignored. The history of their discovery is, like many in science, based on the invention of new technologies. In this case, it was a microscope created by a man named Anton van Leeuwenhoek. But before the Dutchman could make his serendipitous yet groundbreaking discovery in the late 17th century, lens-making technology had to turn several corners and see some other significant findings first.

In the 14th century, crude lenses were being fabricated in Europe for correcting vision. Toward the end of the 16th century, the Dutch began to use Venetian glass, the clearest and the highest quality glass available, to fashion relatively high-quality lenses.

Early in the 17th century, two Dutch lens-makers fashioned a telescope by pairing a concave and a convex lens in a tube. Although the instrument was not much more than a crude spyglass, having a magnification of about seven- or eightfold, it was a huge breakthrough in technology at the time.

In 1609, Galileo Galilei, using a telescope made in Italy from a Dutch lens-maker's design, observed that the moons of Jupiter orbited that planet rather than the Earth. Although Galileo's instrument had a magnification of only about twentyfold, it was sufficient to allow him to zoom in on what we already could see with our naked eyes: planets, stars and the moon. His observations threatened the prevailing Ptolemaic, or geocentric, understanding of the solar system and changed the way we think about our planet, ourselves and our special relationship to the universe.

Although stories of Galileo and his telescope abound, a somewhat lesser-known fact is that he also developed a microscope around 1619. It was simply an inadvertent outgrowth of the invention of the telescope, since it had been known for several years that by inverting a telescope with two lenses, one could magnify objects nearby. So, the optical design of the telescope was inverted and put into a new housing.

The microscope was smaller than its counterpart, and the two lenses were set in a barrel made of leather and wood. Regardless, Galileo did not seem to have much interest in what he saw with his inverted telescope. He appears to have made little attempt to understand, let alone interpret, the smallest objects he could observe. In fact, it was so irrelevant to him that he didn't even give it a name. It wasn't until 1625 that his peers decided to call it *microscopio*.

ON THE SCALE OF MICROSCOPIC STRUCTURES, WE ARE VIRTUALLY BLIND. IF WE CAN'T EVEN UNDERSTAND THAT THERE IS A MICROBIAL WORLD, WHY WOULD WE LOOK FOR IT?

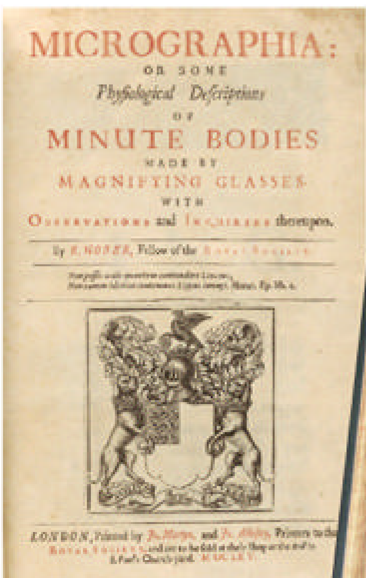
A CLOSER LOOK

The difference between the telescope and the microscope is not simply the configuration of lenses; it is also in human perception and the anticipation of what is seen. While the lack of perception may be partially due to hubris, I think most often it is the lack of looking for patterns in nature in places that are not normally accessible to our limited senses. We can see objects far away with our naked eyes. Comets, meteorites, planets, moons, stars and even exploding stars can be seen without a telescope, and hence, when they are brought closer for inspection with such an instrument as the telescope, these distant objects are not so mysterious, just somewhat so. However, our eyes cannot see something much less than the width of a hair (about a tenth of a millimeter) without the aid of a magnifying device. On the scale of microscopic structures, we are virtually blind. If we can't even understand that there is a microbial world, why would we look for it?

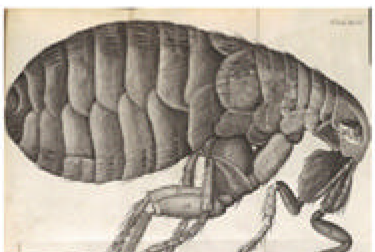
The discovery of the microbial realm, like so many findings in science, was an accident that changed the world as profoundly as Galileo's observations. It required a focusing of the mind as much as of an instrument. The breakthrough came in 1665, when the English Royal Society published the first popular science book, *Micrographia* (with the subtitle *Or Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses With Observations and Inquiries Thereupon*). It was written by Robert Hooke, then a 30-year-old hunchbacked, cantankerous, neurotic hypochondriac who was also a brilliant natural scientist, polymath and an original fellow of the society that published the book.

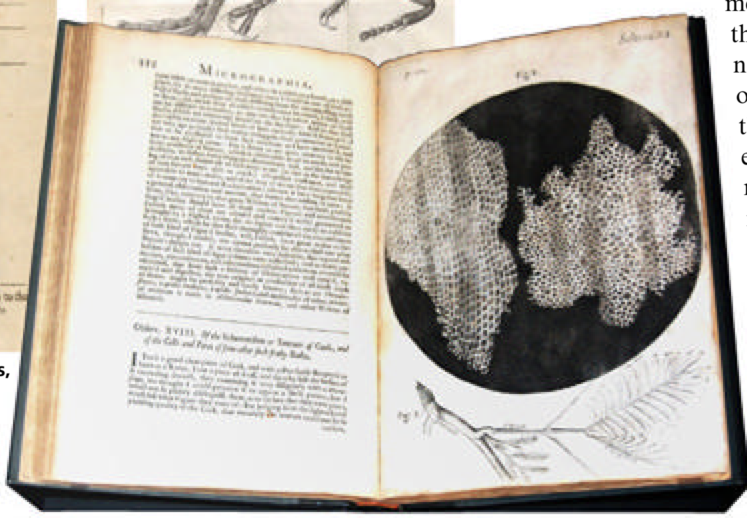
Micrographia captured many people's imaginations. In it, along with dozens of beautiful engravings based on meticulous illustrations by the author, Hooke provided not only a clear description of the architecture of fleas, the seeds of thyme, the eyes of ants, the internal makings of sponges, microscopic fungi and the small building blocks of plants, but he also provided a detailed description of his own microscope.

Hooke's observations were based on a


MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES
WITH
OBSERVATIONS and INQUIRIES thereupon.

Robert Hooke's detailed illustrations, published in 1665, opened up the microscopic world even though microbes were not discovered yet.





Hooke's sketches included a flea (left) and cork bark (below).

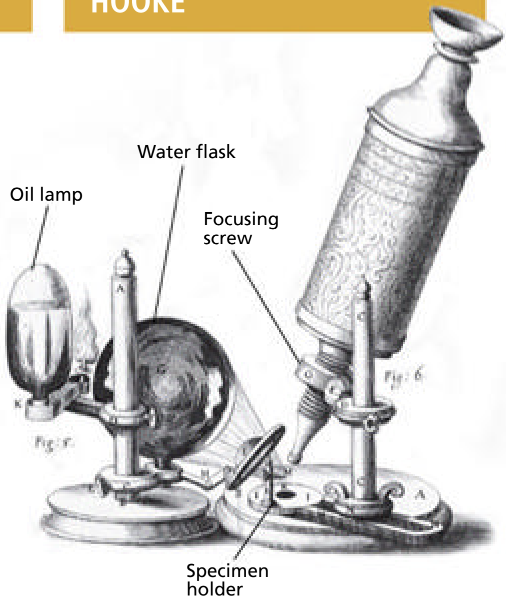
ALL IMAGES: NIH/U.S. NATIONAL LIBRARY OF MEDICINE

THE FIRST MICROSCOPES

GALILEO

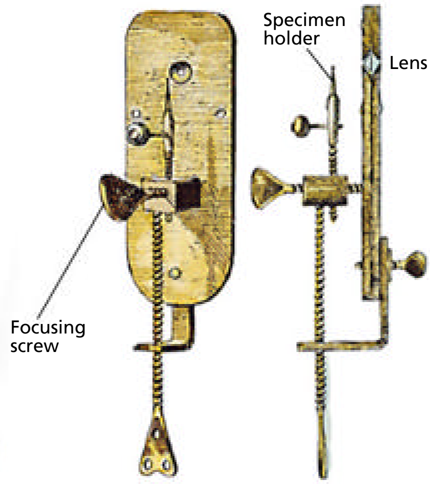
An early example of a microscope, which many historians believe was invented by Galileo in the 17th century.

HOOKE



Hooke's illustration of his own microscope, published in *Micrographia*. His model had a magnification of about twentyfold.

LEEUWENHOEK



An illustration of one of Leeuwenhoek's microscopes. Surviving models from his collection can magnify more than 200 times.

relatively simple compound microscope that had two lenses. Instrument-makers at the time were familiar with telescopes and designed microscopes with two lenses, very similar to that of Galileo's. But two-lensed microscopes had a big, unanticipated problem that telescopes did not. In such simple compound microscopes, the first lens created a halo of many colors that the second lens magnified. The result was that the more one magnified the object, the more distorted the image became.

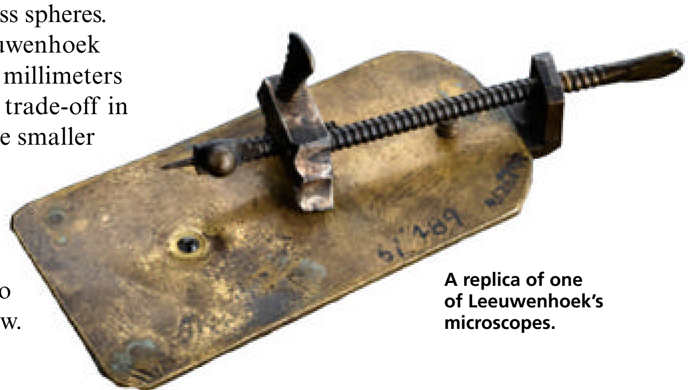
The microscope Hooke used was well made by the standards of the time, but the optics were still poor. It suffered from the large optical aberration that lens-makers could not avoid. The best instrument, regardless of how lovingly the fabricator decorated it, could magnify an object only by about twentyfold before it became almost worthless. Even at such low magnification, the images were fuzzy, and sometimes a bit of imagination was required to reconstruct the structure of the object in view. Regardless, Hooke's skillful illustrations were mind-boggling at the time, and the publication of *Micrographia* sparked interest in the construction of better lenses.

A CURIOUS FIND

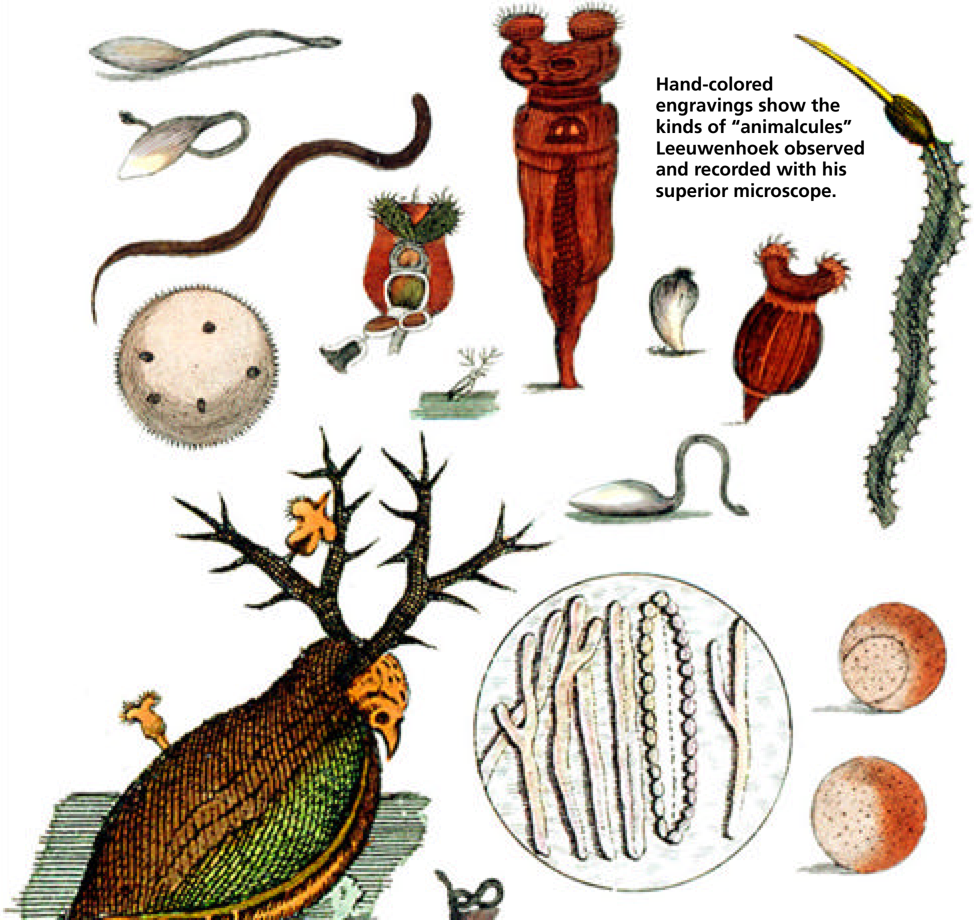
It was around this time — in 1671, specifically — that Anton van Leeuwenhoek, a Dutch fabric merchant in Delft, developed a new but far less ornate microscope with smaller, simpler and, ironically, better optics that allowed much higher magnification without the distortion of the more complicated, expensive instruments. Rather than using two lenses, Leeuwenhoek pulled hot glass rods to form threads and then reheated the threads to form small glass spheres.

The glass spheres Leeuwenhoek used were about 1½ to 3 millimeters in diameter. There was a trade-off in the design of the lens: the smaller the lens, the higher the magnification, but also the smaller the field of view. He used the best Venetian glass and had to polish the lenses somehow. The exact technique he used was a secret he never revealed.

Leeuwenhoek constructed about 500 microscopes in his lifetime, and he had a variety on hand at any given moment to suit the purpose of what he was examining. The instruments themselves were relatively simple. A single spherical lens was mounted in a hole between a pair of silver plates. The sample was positioned on the back of the plates and was focused by a screw mechanism. The observer held the instrument up to his eye so that light from the sun or a candle could illuminate the object. The best instruments could magnify more than 200 times. This magnification was about equal to that of the microscope



A replica of one of Leeuwenhoek's microscopes.




Hand-colored engravings show the kinds of "animalcules" Leeuwenhoek observed and recorded with his superior microscope.

my father bought for me when I was 9 years old. Such instruments allow a human to see blood cells as well as animal sperm and single-celled organisms, including the "animalcules" that Leeuwenhoek observed. Indeed, it was the latter that would later be called microbes.

In October 1674, Leeuwenhoek fell ill, and he wrote (in Dutch), "Last winter while being very sickly and nearly unable to taste, I examined the appearance of my tongue, which was very furred, in a mirror and judged that my loss of taste was caused by the thick skin on the tongue." He then went on to examine an ox's tongue with his microscope and saw "very fine pointed projections" containing "very small globules." He was describing taste buds. He then became curious as to how we sense taste and made infusions of various spices, including black pepper, in water.

In 1676, Leeuwenhoek found that a flask of pepper water that had been sitting on a shelf in his study for three weeks had become cloudy. In examining the cloudy water with one of his microscopes, Leeuwenhoek was surprised to find very small organisms swimming around. The organisms were only 1 to 2 micrometers in diameter — about one-hundredth the diameter of a human hair! He sketched the cells and wrote, "I saw a great multitude of living creatures in one drop of water, amounting to no less than 8,000 or 10,000, and they appear to my eye through the microscope as common as sand does to the naked eye."

The discovery of animalcules was itself unforeseen. It was like seeing the moons of Jupiter but without a planet for the moons to orbit. It was a portent of untold numbers of invisible organisms and their presence right here on Earth. Leeuwenhoek had no idea what the organisms really were. He imagined they were literally extremely small animals, containing organs such as a stomach and a heart, just like the large animals we see with our naked eyes.

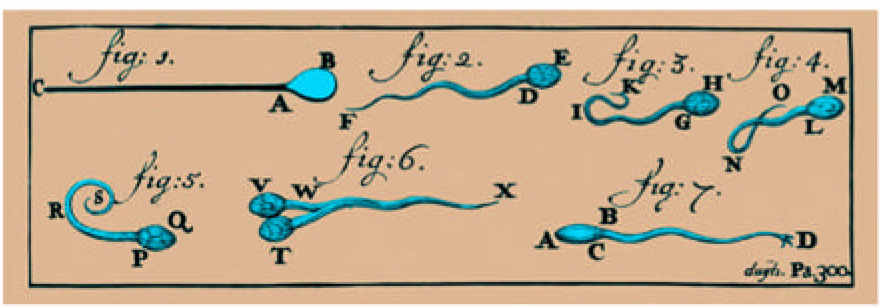
It is truly remarkable that the single-lens instruments made by Leeuwenhoek could allow him to see organisms so small, yet even with the best lenses of the day, he could not resolve their internal structures. However, Leeuwenhoek did something even more profound.

After the discovery of organisms in the pepper water, he examined scrapings from his own mouth. He was astonished to see, for the first time, the presence of animalcules on his teeth and gums. Here, Leeuwenhoek really stood out among the natural scientists; he revealed, for the first time, that we are not alone in our bodies. We are carriers of animalcules.

Indeed, animals like us harbor huge numbers of animalcules and help distribute them around the planet through our excretions and secretions. He also noted that when he drank hot coffee in the morning, the animalcules in his mouth died; it was the first observation that heat killed microbes. Leeuwenhoek went on to describe the various shapes and relative sizes of microbes he found in his own saliva and in other aqueous environments. His simple sketches would later become the basis for microbial taxonomy.

A LASTING LEGACY

When Leeuwenhoek sent a 17-and-a-half-page letter to the Royal Society describing his discovery of animalcules



This engraving from 1707 shows some of the various sperm cells that Leeuwenhoek witnessed. The fabric-maker's powerful microscope enabled him to be the first to observe these little critters.

BOTTOM LEFT: BIOPHOTO ASSOCIATES/SCIENCE SOURCE. ANIMALCULE ENGRAVINGS BY ANN RONAN PICTURES/PRINT COLLECTOR/GETTY IMAGES

for publication in the new, and first, scientific journal, *Philosophical Transactions*, it was met with such skepticism that even Hooke thought it was a delusion. Hooke sent an English vicar and some other reputable observers vetted by the Royal Society to Delft to verify the reports. The observers were as amazed as Hooke and his colleagues in London had been.

In 1677, Leeuwenhoek's now-verified observations were published by the Royal Society (in English, after being translated from Dutch with help from Hooke, who learned Dutch so that he could read Leeuwenhoek's papers). Leeuwenhoek was elected a foreign fellow of the society in 1680, but he never visited London. His descriptions and enumeration of microbes seemed to support the idea of spontaneous generation of life (in pepper infusions no less!), the idea that organisms could be formed from dead or nonbiological sources without any obvious parental lineage. For example, it was commonly accepted that maggots could form in dead meat and that wasps could come from buried elk horns. Spontaneous generation was widely believed by most people at the time. Leeuwenhoek rejected the basic notion, but he could not disprove it.

Even though Leeuwenhoek could not disprove the notion of spontaneous generation of life, his findings showed that he was a creative genius. He had no formal higher education and no affiliation with any university. He did not know Latin or Greek, the two languages of formally educated people at the time; he wrote only in Dutch. He built microscopes as a pastime and gave many of them away; he never sold any. He bequeathed 26 of his instruments to the Royal Society, all of which subsequently were "borrowed" by members of that esteemed group of scientists; all the originals have since disappeared. The rest of his collection was sold for the weight of the silver or other metals in the bodies of the instruments. Over his 90-year lifetime, he sired five children. Only one, Maria, lived beyond childhood, and his scientific legacy almost died with his own death in 1723.

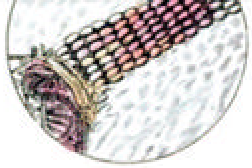
Although Leeuwenhoek is often viewed as the father of microbiology, Hooke was the collaborative agent who led him to fame. Both remarkable men were critical catalysts for the impending discovery of the invisible world. On a personal level, both were extremely generous toward each other to the end of their lives.

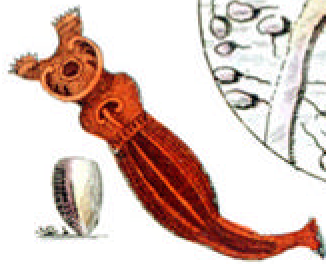
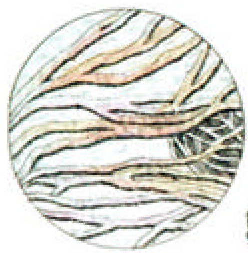
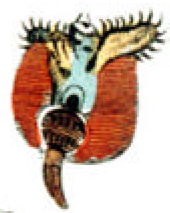
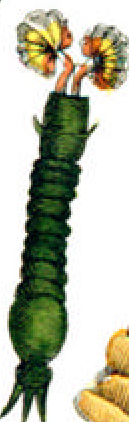
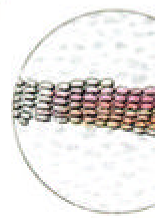
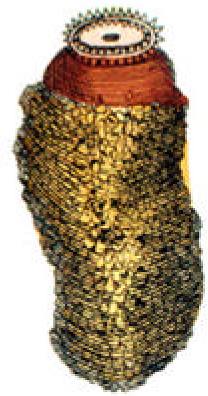
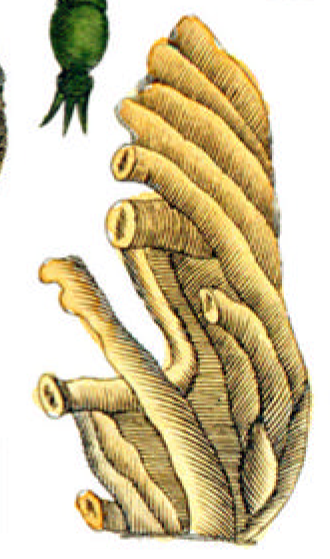
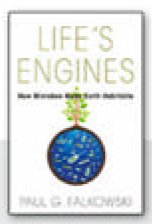
Neither Hooke nor Leeuwenhoek had students, and although *Micrographia* was a big seller in 1665 and for some years afterward, Leeuwenhoek never wrote a book, and his papers were not widely read. Neither Leeuwenhoek nor Hooke had a biological successor, and unlike Galileo, neither had immediate intellectual successors.

Interest in pepper water faded. The role of microbes in biological functions was virtually ignored, and it would be almost 200 years before these organisms would garner further serious attention.

Amazingly, while the fundamental discoveries in science in the 17th century — gravity, light waves, planetary rotation around stars and the incredible abstraction of science in mathematics — spurred huge explosions of discoveries in physics and chemistry, fundamental discoveries in biology largely lagged behind and were important only as they related to human health. And so the microbial world was delegated to an invisible world in the 18th century — as natural philosophers turned to questions about the evolution of plants and animals, and the geologic structures that contained fossil remains of extinct organisms. D

"I SAW A GREAT MULTITUDE OF LIVING CREATURES IN ONE DROP OF WATER, AMOUNTING TO NO LESS THAN 8,000 OR 10,000, AND THEY APPEAR TO MY EYE THROUGH THE MICROSCOPE AS COMMON AS SAND DOES TO THE NAKED EYE." *— ANTON VAN LEEUWENHOEK*



Small Wonders

A California microbiologist is unearthing startling clues about how tiny wetland organisms influence climate.

BY **ELIZABETH SVOBODA**

Tringe is studying how wetland microbes affect climate change at sites like this one at the southern end of San Francisco Bay.

Susannah Tringe grabs a pair of green rubber boots from the back of her truck, pulls them on and wades into a pea-colored pond until she's standing calf-deep. We're just a few miles from Google's main campus in Mountain View, Calif., but from where we're standing, Silicon Valley's urban sprawl is just a faint, hazy blur. Stilt-legged birds skitter along the banks of the pond; cord grass and still water stretch to the horizon.

"This is really mucky," says Tringe, an environmental microbiologist at the U.S. Department of Energy's Joint Genome Institute. "You sink in at every step." She bends down to take a murky water sample, then holds the cup up to the light.

"That looks disgusting," laughs Susie Theroux, a postdoc in Tringe's lab who still wrinkles her nose at the sight of the viscous gunk.

The wetland sludge Tringe and Theroux are sampling isn't just any muck. It holds carbon dioxide-processing microbes that play a key role in climate change dynamics. Wetlands are widely valued as natural pollution filters and as habitat for endangered species such as the Yuma clapper rail, whooping crane and least tern. But they're also a key part of the carbon cycle: Although wetlands cover only about 3 percent of Earth's surface, they account for as much as 30 percent of soil carbon storage. Yet some wetland microbes secrete another potent greenhouse gas, methane, which may cancel out some of the benefits of pulling carbon dioxide from the atmosphere. Tringe is trying to determine just how much wetlands

Susannah Tringe uses a corer to extract soil samples in a wetland on Twitchell Island in the Sacramento-San Joaquin River Delta.

actually help offset climate change.

Those answers will come none too soon. Because of development and sea-level rise, the U.S. loses more than 80,000 acres of wetlands each year, according to a study by the U.S. Fish and Wildlife Service. To offset those losses, as required under the Clean Water Act, the government invests at least $3.9 billion each year to restore degraded wetlands or construct new ones to reach an annual net increase of 100,000 acres of wetlands.

By documenting the biological functions of wetland microbes, Tringe will learn how these tiny organisms affect the greenhouse gas equation, and eventually she'll be able to help restoration experts design projects in a way that enhances climate benefits.

"A better understanding of the wetland microbial community will likely improve our ability to maximize carbon storage in these habitats," says John Bourgeois, who manages California's South Bay Salt Pond Restoration Project.

A TALL ORDER

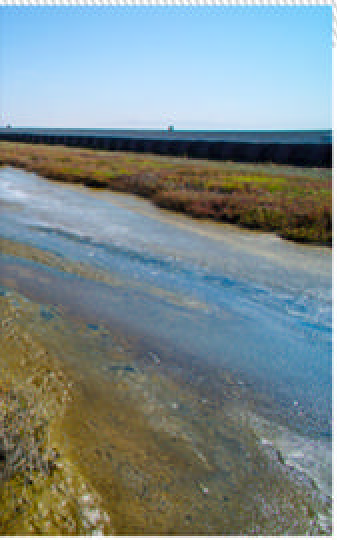
To figure out just how microbial processes in wetlands work, Tringe and her team are building a catalog of wetland microorganisms and the biological tasks they carry out. "We've been collecting samples in a lot of places to analyze DNA and RNA," Tringe says. "We're generating the wetlands metagenome."

Tringe began exploring this idea of teasing out microbial functions in wetlands after joining the Joint Genome Institute in 2006. She knew it would be a tall order to sequence the complete genome of every single microbe in a given wetland area; the computing power required would be staggering, and many microbes don't survive long when cultured in the lab.

But thanks to a mid-2000s postdoc stint with geneticist Edward Rubin at Lawrence Berkeley National Laboratory, Tringe had a potential solution. Rubin introduced her to a then-novel discipline called metagenomics, which involves sequencing the *collective* genome of all the microbes in a given location.

To perform this type of sequencing,

CLOCKWISE FROM LEFT: DAVID GILBERT/DOE JOINT GENOME INSTITUTE; ROY KALTSCHMIDT/BERKELEY LAB; GILBERT; KALTSCHMIDT



Top: Vials of soil collected from Twitchell Island. Above: Tringe (right) and postdoc Susie Theroux take water samples at a salt pond near Palo Alto, Calif.

scientists use chemicals to extract the genetic material from an environmental sample — say, a cup of dirty water — which typically contains many different organisms. They run cloned snippets of the extracted material through a sequencing machine, which reads out the nitrogen, sugar and phosphate bases that make up each short segment. After these segments are pieced back together, they reveal the distinct gene sequences of the millions of microbes in the sample. The result: a broad overview of the microbial community and the functions each microbe performs within the ecosystem.

The approach has turned out to be a perfect fit: It's given Tringe a wide-ranging snapshot of the biological processes at work in wetland microbial communities. If she finds a large number of genes governing processes that tuck away carbon dioxide, for example, the wetland likely has high carbon storage potential. But if she finds many genes that code for processes involved in methane production, the wetland may be contributing high levels of this potent greenhouse gas to the atmosphere.

A MICROBE MYSTERY

Before Tringe's team can perform this genetic analysis, though, they have to get the raw material. As we stand on the bank of the salt pond, the midday sun beating down, Theroux brandishes a 3-foot-long instrument that looks like a fat blowgun. "This is what we call our intact corer," she explains. "It maintains the soil sample as it was." Wearing a pair of waders, she sloshes into the pond. Submerging the end of the corer, she twists the blade assembly and pulls up a sample from the bottom. It has the appearance and consistency of chocolate ice cream, but it smells like bad breath. Theroux transfers the mud to a jar so that it can be run through DNA and RNA sequencers back at the lab.

Tringe's sampling has turned up some evidence that certain landscape characteristics influence microbial populations in ways that affect greenhouse gas emissions and carbon storage. Saltier wetland areas, for example, tend to attract microbial communities that give off less methane, as do areas with more active water flows. "We're starting to be able to predict which sites might produce more or less methane," Tringe says. "We might be able to say, 'Right here, it would be better if there were lots of fresh water coming in.'" Tringe and her team initially thought wetland soil with lots of organic matter might attract methane-producing microbes, but they've since found that's not usually the case — which means it could be highly suitable for restoration projects.

To her surprise, though, Tringe also found that restored wetlands harbor microbial communities that produce methane at higher rates than communities in undisturbed wetlands. Tringe speculates the faster pace of plant growth in restored wetlands may accelerate biological processes that emit methane.

But that doesn't mean wetlands shouldn't be restored, she says. Tringe suspects these wetlands probably do not sustain high methane production for long. As initial rapid plant growth levels off, she believes, microbial communities' methane production will also slow — and meanwhile, the wetlands are still storing massive amounts of carbon. "If for the next few centuries they're carbon sinks, they'll make up for those methane emissions we see in the first few years," she says.

Data are still limited, so Tringe cannot definitively say how wetland restoration planners can best limit emissions while keeping carbon storage processes intact. She and her team are planning many more sampling missions to expand their genetic Rolodex.

Ultimately, Tringe wants to create computer simulations that would allow wetland experts to analyze the potential greenhouse gas effects of various restoration strategies, such as tweaking salinity, introducing moving water or adding plants. But what fires Tringe's imagination even more than shaping wetlands' environmental legacy is mapping a microbial universe that has long been shrouded in mystery.

"The analogy we use is the human genome. Most medical research today heavily depends on it, but people don't think about the fact that it had to be generated," she says. "If you have a better blueprint, you're going to have a much better chance of really understanding the wetlands." D

***Elizabeth Svoboda** is a science writer in San Jose, Calif., and the author of* What Makes a Hero?: The Surprising Science of Selflessness.

Making a Mark

New analysis of old finds upends conventional wisdom about where and when the first artists evolved. Hint: They weren't *Homo sapiens*.

BY **JONATHON KEATS**

In the 1880s, a young Dutch anatomist named Eugène Dubois set out to find the missing link between apes and humans. He chose to look in Indonesia, reasoning that gibbons resembled *Homo sapiens*. After four years of searching, he uncovered a skullcap with a simian-like brow ridge and a large brain case, along with other fragmentary fossils, buried near the Solo River on the Indonesian island of Java. Dubois' "Java Man" became a lightning rod for debate at a time when many in the scientific community still resisted the idea that humans evolved from anything.

Dubois' missing-link claim was eventually disproven. Java Man was reclassified in the 1950s as *Homo erectus* and is now called Trinil 2, in reference to the excavation site.

But Java Man wasn't done causing a stir. Found with the fossils by Dubois, but not studied closely until recently, were artifacts that could help rewrite the story of human cognitive development.

The evidence was stashed away at Leiden's natural history museum in the Netherlands, where the Dubois Collection has been stored for more than a century. In 2007, an Australian National University Ph.D. candidate named Stephen Munro was studying prehistoric hominin habitats by examining fossil mollusks. Passing through Leiden, he photographed some ancient shells that Dubois had collected with the *H. erectus* skullcap. On one of them, Munro spotted a zigzag pattern.

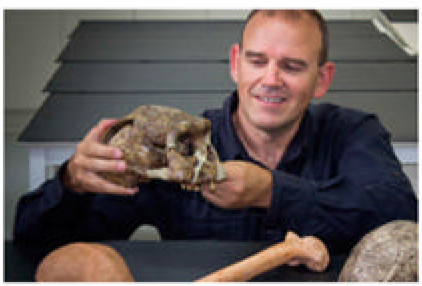
Munro's first thought was that the engraving must be human. His second thought: Some rogue curator might have done it as a practical joke. So he wrote to Josephine Joordens, his colleague at Leiden University, to ask her opinion.

Along with his famous Java Man fossils, 19th-century anatomist Eugène Dubois collected shells with small holes that appeared to be made by shark teeth (inset) at the site.

SHELL SHOCKED

An archaeologist and marine biologist, Joordens was studying Dubois' shells to understand Java's prehistoric environment. She and a colleague had already noticed another strange quality: Many of the shells had small holes near their hinges. The holes seemed to have been made with shark teeth, a number of which were found with the fossils. Pressed through the shell with a strong thumb, a tooth would have severed the ligament holding the mussel shut, forcing it open to provide — *voila!* — a happy meal.

Dating of the sediments established that the shells found at the Solo River site were between 430,000 and 540,000 years old, making the holes the earliest case of deliberate puncturing. The discovery predates the oldest known beads in Africa by hundreds of thousands of years. While researchers cannot definitively say there is a connection between the holes and the zigzag, "the act of engraving was probably discovered in the context of opening shells for food with a sharp tool," Joordens notes.



Stephen Munro, holding the skullcap of Trinil 2, aka "Java Man," discovered the oldest known engraving on shells found near the fossil.

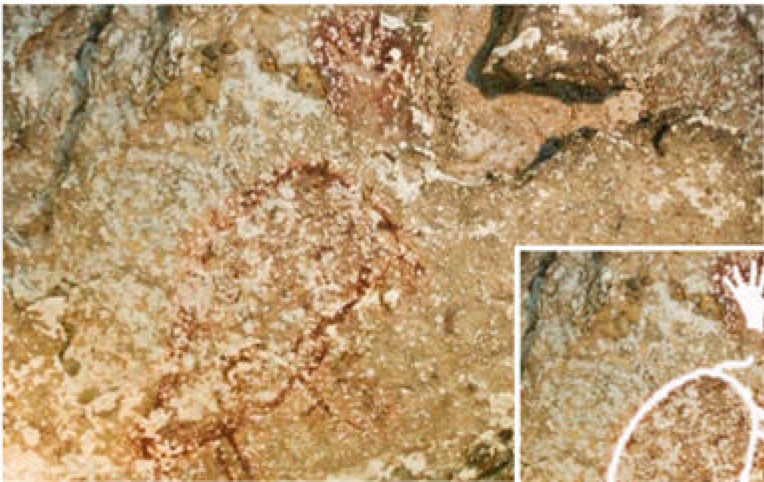
Under the microscope, the etching showed the zigzag had undergone millennia of weathering, confirming the marks were more than 300,000 years older than the previously oldest known engraving: a zigzag etched into a piece of ochre by an anatomically modern human in Blombos Cave, South Africa.

"I was really quite blown away when the paper was published in *Nature*," says George Washington University paleoanthropologist Alison Brooks. Although there's no way to know whether the zigzag was communicative or mere doodling, she marvels at the inventiveness of our distant ancestors.

Munro, now curator of the National Museum of Australia, attributes the innovation to the mutability of island habitats, which would require constant

THIS PAGE, CLOCKWISE FROM TOP LEFT: FRANK WESSELINGH/NATURALIS; HENK CASPERS, NATURALIS; PHIL DOOLEY/AUSTRALIAN NATIONAL UNIVERSITY. OPPOSITE: WIM LUSTENHOUWER/VU UNIVERSITY AMSTERDAM

Under the microscope, the etching showed that the zigzag had undergone millennia of weathering, confirming that the marks were more than 300,000 years older than the previously oldest known engraving.



New dating of Indonesian cave art is rewriting the evolution of creativity. The local pig-deer drawing above is outlined in white at right, alongside a hand stencil.

adaptation. "It's no coincidence that this area is such a dynamic place," he says, also citing the recent discovery — published in *Nature* last October — of the world's oldest known figurative art, on the neighboring island of Sulawesi.

Unlike the engraved Javanese shell languishing in museum archives, Sulawesi's revolutionary cave paintings have been hiding in plain sight. They've been a tourist attraction for decades: stylishly drawn wild animals and silhouettes of human hands enlivening dozens of limestone karsts on the forested southwestern end of the island. Because cave paintings deteriorate quickly in island humidity, scientists always assumed the paintings must be less than 10,000 years old.

Then one day in 2011, a Griffith University archaeologist named Adam Brumm noticed that some of the artwork was covered with calcite growths colloquially known as cave popcorn. That meant they could be dated by measuring radioisotopes using new techniques mastered by Brumm's colleague at Griffith, Maxime Aubert.

Aubert cut samples of the cave popcorn, shaving the calcite into ultrathin layers in a process he calls micro-excavating. For each sample, he measured the ratio of uranium to thorium, a byproduct of radioactive decay. The proportions gave him the minimum age of the underlying art. A drawing of a local beast known as a pig-deer was at least 35,400 years old, and one of the hand stencils was created at least 39,900 years ago — older than animal paintings in France's Chauvet cave, the earliest known example in Europe.

REDRAWING HISTORY

These artworks pose a serious challenge to conventional wisdom about the development of our species. Ever since 1880, when the first prehistoric paintings were discovered in Spain's Altamira Cave, most paleontologists have assumed that humans became fully modern in Europe about 35,000 years ago. European cave paintings were seen as evidence of a "creative explosion" sometimes attributed to a brain mutation, a theory reinforced by the apparent age discrepancy between figurative art in Europe and other, more recent art elsewhere.

"There was a long time when people thought Africans had nothing to do with the rest of the world after the first human ancestors left Africa 2 [million] to 1.8 million years ago," Brooks explains. The fact that Europe is not uniquely the seat of the earliest art "argues very strongly that the humans who left Africa had the capacity to make images and to make symbols," she says, "and they probably had it for a while."

Anthropologist Paul Taçon — a Griffith University colleague of Aubert and Brumm who was not involved in their study — concurs, connecting the Sulawesi paintings to the Javanese shell engraving. "We don't give our ancestors enough credit," he quips. "A lot of what we thought was invented by modern humans probably goes back much further in time." The age-old process of migration and adapting to unfamiliar circumstances may have spurred artistic expression through countless small, creative explosions. "Abstract design was probably something that archaic humans engaged in for hundreds of thousands of years," Taçon says.

The search for the origins of art is going global. Taçon is currently studying rock art in Australia, China and Malaysia. Brooks is scrutinizing cave paintings in Namibia. Aubert is looking at rock shelters in Borneo. And Joordens is returning to the site first dug up by Dubois, in search of the masterpieces Java Man may still be hiding. D

__Jonathon Keats__ is a San Francisco-based journalist and art critic. His favorite artists include Marcel Duchamp and Java Man.


HARBOR FREIGHT
QUALITY TOOLS AT RIDICULOUSLY LOW PRICES
How Does Harbor Freight Sell GREAT QUALITY Tools at the LOWEST Prices?
We have invested millions of dollars in our own state-of-the-art quality test labs and millions more in our factories, so our tools will go toe-to-toe with the top professional brands. And we can sell them for a fraction of the price because we cut out the middle man and pass the savings on to you. It's just that simple! Come visit one of our 550 Stores Nationwide.
SUPER COUPON
20% OFF
ANY SINGLE ITEM
LIMIT 1 - Save 20% on any one item purchased at our stores or HarborFreight.com or by calling 800-423-2567. *Cannot be used with other discount, coupon, gift cards, Inside Track Club membership, extended service plans or on any of the following: compressors, generators, tool storage or carts, welders, floor jacks, Towable Ride-On Trencher, Saw Mill (Item 61712/62366/67138), Predator Gas Power Items, open box items, in-store event or parking lot sale items. Not valid on prior purchases after 30 days from original purchase date with original receipt. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
SUPER COUPON
FREE
WITH ANY PURCHASE
CEN-TECH
7 FUNCTION DIGITAL MULTIMETER
LOT 98025 69096 90899 shown
$14.99 VALUE
LIMIT 1 - Cannot be used with other discount, coupon or prior purchase. Coupon good at our stores, HarborFreight.com or by calling 800-423-2567. Offer good while supplies last. Shipping & Handling charges may apply if not picked up in-store. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one FREE GIFT coupon per customer per day.
SUPER COUPON
RAPID PUMP® 3 TON LOW PROFILE HEAVY DUTY STEEL FLOOR JACK
SAVE $90
PITTSBURGH
LOT 68049/62326 62670/61282/61253 shown
• Weighs 77 lbs.
$79.99 REG. PRICE $169.99
LIMIT 4 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
SUPER COUPON
27 LED PORTABLE WORKLIGHT/FLASHLIGHT
LOT 67227 shown 69567/60566/62532
SAVE 62%
Batteries included.
$2.99 REG. PRICE $7.99
LIMIT 8 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
WOW SUPER COUPON
3 GALLON 100 PSI OILLESS HOT DOG STYLE AIR COMPRESSOR
CENTRAL PNEUMATIC
SAVE 55%
LOT 69269/97080 shown
$39.99 $62.99
REG. PRICE $89.99
LIMIT 3 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
SUPER COUPON
• 1000 lb. Capacity
MOVER'S DOLLY
HaulMaster
LOT 60497/93888 shown 61899/62399
$8.99 REG. PRICE $14.99
SAVE 40%
LIMIT 7 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
SUPER COUPON
10" SLIDING COMPOUND MITER SAW
CHICAGO ELECTRIC POWER TOOLS
SAVE $115
LOT 61307 61971/61972 98199 shown
$84.99 REG. PRICE $199.99
LIMIT 4 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
WOW SUPER COUPON
9 PIECE FULLY POLISHED COMBINATION WRENCH SETS
PITTSBURGH
SAVE 62%
SAE LOT 69043 42304 shown
METRIC LOT 42305 69044
YOUR CHOICE!
$5.99 $8.99
REG. PRICE $15.99
LIMIT 5 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
WOW SUPER COUPON
1/2" INDUSTRIAL QUALITY SUPER HIGH TORQUE IMPACT WRENCH
• 700 ft. lbs. Max. Torque
CENTRAL PNEUMATIC EARTHQUAKE
SAVE OVER $56
LOT 62627 68424 shown
$73.13 $99.99
REG. PRICE $129.99
LIMIT 4 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
SUPER COUPON
PITTSBURGH AUTOMOTIVE
3 TON HEAVY DUTY STEEL JACK STANDS
SAVE 55%
LOT 38846 shown 69597/61196 62392
$19.99 REG. PRICE $44.99
LIMIT 6 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
SUPER COUPON
27", 11 DRAWER ROLLER CABINET
LOT 61485 67421 shown
SAVE $200
$159.99 REG. PRICE $359.99
LIMIT 3 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
SUPER COUPON
WINDSOR DESIGN
60", 4 DRAWER HARDWOOD WORKBENCH
SAVE $110
LOT 69054 62603 93454 shown
$139.99 REG. PRICE $249.99
LIMIT 3 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
WOW SUPER COUPON
10 FT. x 20 FT. PORTABLE CAR CANOPY
SAVE $80
LOT 60728 69034 shown
$119.99 $149.99
REG. PRICE $199.99
LIMIT 5 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
SUPER COUPON
18 VOLT CORDLESS 3/8" DRILL/DRIVER WITH KEYLESS CHUCK
drillmaster
SAVE 54%
Includes one 18V NiCd battery and charger.
LOT 69651 68239 shown
$15.99 REG. PRICE $34.99
LIMIT 7 - Good at our stores or HarborFreight.com or by calling 800-423-2567. Cannot be used with other discount or coupon or prior purchases after 30 days from original purchase with original receipt. Offer good while supplies last. Non-transferable. Original coupon must be presented. Valid through 9/12/15. Limit one coupon per customer per day.
• 100% Satisfaction Guaranteed
• Over 25 Million Satisfied Customers
• No Hassle Return Policy
• Lifetime Warranty On All Hand Tools
• 550 Stores Nationwide
• HarborFreight.com 800-423-2567

Open the Solar System's Express Lane!

Advances in spaceship propulsion are speeding up.

BY COREY S. POWELL

NASA's Space Launch System is designed to send humans back beyond Earth orbit.

BOEING

On Jan. 19, 2006, the New Horizons spacecraft roared off the pad in Cape Canaveral, Fla., and into the record books. Perched atop a giant Atlas V rocket, the lightweight probe accelerated to about 36,000 mph, the fastest object ever launched by humans. It outdistanced the moon in nine hours, reached the orbit of Mars in 11 weeks and swung around Jupiter in February 2007. Then came the great wait.

New Horizons will fly by Pluto this July and, if all goes well, return the first detailed images of the diminutive world and its moons. Those observations will take place more than nine years after the probe was launched, and 43 long years after the original plans for a Pluto mission. Worse, New Horizons represents an end as much as a beginning. No nation on Earth is actively planning another probe to Saturn or beyond. We are entering a period of deep interplanetary drought.

The problem is as easy to state as it is hard to solve: Space travel takes too damn long. Careers begin and end in the time it takes to mount an expedition to the outer solar system. Lives end, too. In a recent exploration strategy meeting at NASA's Ames Research Center, Peter Tsou of the Jet Propulsion Laboratory warned his colleagues that getting a spacecraft to Saturn's moon Enceladus might be a "multigenerational" undertaking.

The sluggish pace exacerbates the perpetual mismatch between NASA's ambitions and its budget. Long missions require a rare investment of steady, patient funding and produce a payoff that may arrive long after current politicians have left the scene.

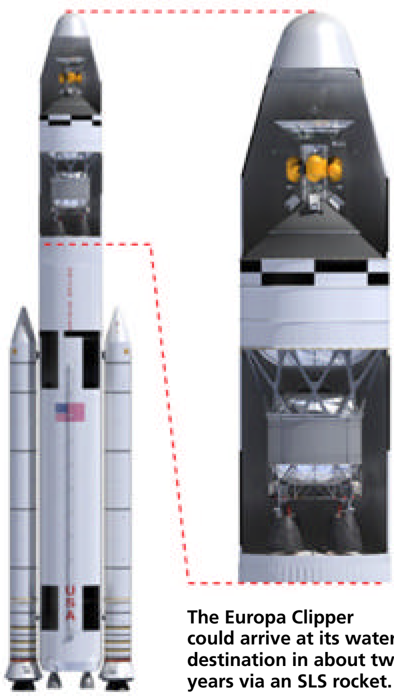
And yet, the outer solar system is where a lot of the most interesting real estate awaits. This is where you find two extraordinary Saturnian moons: Titan, home to dozens of methane lakes, and Enceladus, which shoots out geysers laced with organic compounds. This is the realm of the dormant comets and Kuiper Belt objects that record how the solar system formed and how Earth got its water. If we want to understand the origins of

our planet, and of ourselves, this is where we need to go.

WE'RE GONNA NEED A BIGGER ROCKET

The most obvious way to accelerate the process is to literally *accelerate the process* by latching onto a bigger, more powerful engine. This will be the likely approach for the Europa Clipper, which finally seems headed for approval after a long series of stops and starts. Tentatively slated for a 2022 launch, the probe will orbit Jupiter and make about 45 passes by the giant planet's moon Europa, which has a global ocean just beneath its ice-covered surface. Astrobiologists consider Europa one of the most promising places to look for alien life; the probe will study its landscape and chemistry to investigate and, perhaps, to make way for a future lander.

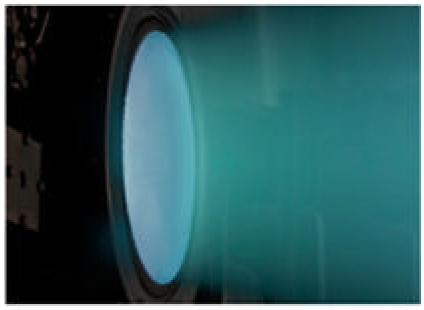
In its current conception, the Europa Clipper will fly atop NASA's upcoming Space Launch System, or SLS, an enormous rocket meant to carry humans into deep space. Launching on an Atlas V, like New Horizons, the Clipper would take at least six years to reach Europa. The SLS will complete the trip in one-third the time. That's more like it.



The Europa Clipper could arrive at its watery destination in about two years via an SLS rocket.

If you have faith in NASA, more exciting rocketry options are coming soon. In conjunction with the SLS, the agency plans to develop a new solar-electric propulsion system (called SEP, because everything at NASA gets an acronym) powerful enough to grab a large chunk of asteroid and tow it into orbit around our moon. This system uses huge solar panels to generate electricity, which will energize stored xenon gas and expel it at high velocity to generate thrust. The idea is to capture a small asteroid, bring it into orbit around the moon using SEP, and then send astronauts to explore it — a daring and politically contentious concept called the Asteroid Redirect Mission.

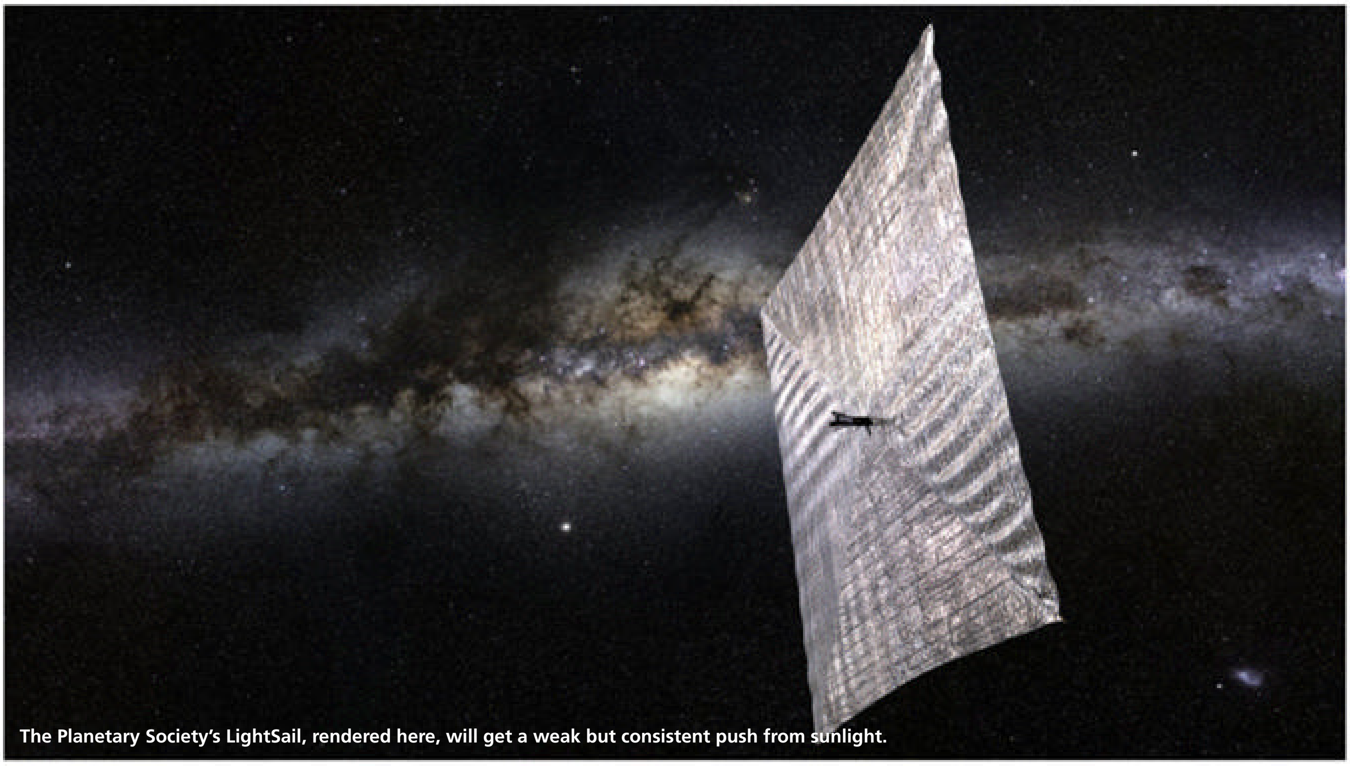
Assuming the tech comes together as intended, it has delicious possibilities for unmanned exploration as well, as Nathan Strange from NASA's Jet Propulsion Laboratory explained in another presentation at the Ames strategy meeting. He calculates that a solar-electric engine mounted on an SLS rocket could ferry 28,000 pounds of cargo (equivalent to the Cassini probe plus eight Curiosity rovers) to Saturn in five years. Ah, the possibilities — and the caveats. The SLS does not exist yet. The SEP is still under development and may never happen. And this new, complex hybrid approach would likely not be cheap.



Top: The Dawn spacecraft used an efficient ion engine to visit Vesta (left) and Ceres (right) in this artist's rendering. Above: An ion thruster fires at a test facility in Cleveland.

Even if you don't have faith, though, there is good news. A more modest version of the solar-electric propulsion technology is already available and hard at work, propelling the Dawn spacecraft currently circling the dwarf planet Ceres in the asteroid belt. Dawn's xenon engine doesn't produce a lot of thrust, but it can keep firing for months or even years, building speed and changing course. That engine is what allowed the spacecraft to orbit the asteroid Vesta, break free, then orbit Ceres. There's no reason why we couldn't repeat the experiment with a whole fleet of similar probes, sending each one to multiple destinations using

FROM TOP: NASA (2); BOEING



The Planetary Society's LightSail, rendered here, will get a weak but consistent push from sunlight.

simple and cheap xenon engines.

Or we could go further and do away with fuel entirely. By the time you read this, the nonprofit Planetary Society should have launched a test version of a solar sail, a giant space kite that flies by harnessing the pressure of sunlight. NASA and the Japanese space agencies have flown basic prototypes as well. Even more so than a xenon engine, a space sail produces only a feeble push. But it is fundamentally inexpensive, inexhaustible and endlessly scalable. The bigger you build the sail, the more thrust you get. Tack into the photon wind, and you can steer wherever you want.

SPEED UP BY SLOWING DOWN

If you are reading closely, you may have noticed that I've pulled a major switcheroo on you. I started out talking about going faster and ended up describing ways to go even slower. Xenon engines and solar sails are tortoises in the space race, and the low-energy paths that put them to best use can take many years to complete. But paradoxical as it sounds, slowing down might be the most effective way to speed up space exploration.

The long wait between launch and arrival is a big problem, yes, but the chasm of time between mission starts is an even bigger one. Right now there is a frustrating lack of any steady, consistent cadence to our exploration of the outer solar system. "Cadence" is a word I heard repeatedly at Ames, often expressed in a pleading tone. Without it, graduate students move to other fields, engineers head elsewhere in search of work, infrastructure crumbles, public interest drifts and funding becomes even harder to sustain.

Fortunately, cadence is a lot easier to address than the issue of speed. In this case, we already know the solution: design a lot of relatively low-cost, high-impact missions and schedule the launches so that notable new results keep coming in every year or two, not every decade or two. Xenon drives and space sails are both plausible parts of that plan. Miniaturized "CubeSat" probes, microlanders and a mix of short-duration daredevil missions and slow-going, multidestination voyagers are essential components as well. Numerous modest missions should actually make it easier to do a few big-budget shock-and-awe undertakings, like sending a submarine to Titan or sniffing those Enceladus geysers for signs of life.

New Horizons and Dawn are steps in the right direction. The former cost one-quarter as much as the Curiosity rover on Mars, the latter about one-sixth. More sobering, their combined cost, over their entire 15 years of operation, is roughly equal to the cost of 10 F-35 fighter jets.

The outer solar system is ours for the taking. All we have to do is overcome the greatest obstacle: not the rocket equation, but human inertia. D

***Corey S. Powell**, editor at large of* Discover, *also writes the magazine's Out There blog. Follow him on Twitter,* **@coreyspowell**

JOSH SPRADLING/THE PLANETARY SOCIETY

CLASSIFIEDS

Testosterone

BY LEAH SHAFFER

The manly hormone evolved 500 million years ago — from estrogen.

Testosterone builds muscles and lean body mass, as shown in Michelangelo's sketch of David.

1 Testosterone is produced in men's testicles, women's ovaries and the adrenal glands of both sexes. In the early weeks of pregnancy, it kicks off the development of reproductive organs for males. **2** After birth, testosterone plays a role in regulating processes from fat distribution to red blood cell production. **3** Long before the hormone was discovered, people ascribed youth-restoring powers to the testicles. Roman naturalist Pliny the Elder noted the sexually stimulating effects of dining on hyena genitals (with honey, of course). **4** Honeyed hyena testes sound preferable to the handiwork of Kansas huckster John Brinkley, who inserted slices of goat scrotum into men's testicles in the 1920s, claiming it would boost virility and cure a host of ailments. **5** Despite its association with male virility, testosterone can also enhance a woman's libido by targeting receptors in a section of the brain responsible for sexual activity. **6** Sex hormones, including testosterone, evolved 500 million years ago — before the first vertebrate animals — from the "mother" of all steroid hormones, estrogen. **7** But testosterone is, relatively speaking, a manly hormone. Normal levels for women are 5 to 7 percent of those for men. **8** Testosterone levels decline with age. Fifty percent of men in their 80s have testosterone levels below the normal adult male range. **9** One thing that's not declining: demand for testosterone. In 2010, 1.3 million patients in the U.S. received a prescription for the hormone. That number jumped to 2.3 million in 2013. **10** Age isn't the only cause of low testosterone; obesity is, too. With more body fat, more testosterone gets converted to an estrogen called estradiol, which further inhibits testosterone production.

11 Low T from obesity is a particularly vicious cycle because testosterone builds muscle apparently by stimulating the production of growth hormone releasing hormone (GHRH), which correlates with lean body mass. **12** Yet it's not clear if the benefits of testosterone treatments outweigh the risks. Some studies have found an increased risk for cardiovascular disease among older men after starting testosterone therapy. Other studies suggested a decreased risk in overall mortality. **13** The hormone was first synthesized in 1935 after initial isolation of another male hormone called androsterone, which was distilled from some 4,000 gallons of donated urine. **14** Dutch researchers coined the term *testosterone* that same year. **15** There are more than 30 kinds of anabolic-androgenic steroids — the infamous 'roids used and abused to promote muscle growth — but they are all synthetic compounds mimicking testosterone's chemical structure. **16** There is some correlation between aggressive behavior and testosterone levels, but most research lacks evidence of causation, and some results are contradictory. **17** One study found higher levels of testosterone correlated with aggressive behavior in 12- and 13-year-old boys, but not in 15- and 16-year-old boys. Studies on nonhumans have found much stronger correlations between aggression and testosterone levels. **18** The impact and timing of testosterone production varies greatly among species. For humans, testosterone production kicks in prenatally to differentiate the sexes, but production of testosterone in rats ramps up only after birth. **19** There's scant evidence to support "natural" testosterone boosters: Elk antler velvet had no lasting effect on T levels, but royal jelly worked wonders — on hamsters. **20** Mixed research results aren't slowing the testosterone booster bandwagon. In 2013, 25 percent of individuals taking it started treatment without bothering to get a blood test to see if they actually had low T, according to the FDA. D

***Leah Shaffer** is a science writer based in St. Louis. A drugmaker-sponsored online quiz once told her she had low testosterone. But she is, after all, a woman.*

THE GALLERY COLLECTION/CORBIS

DISCOVER (ISSN 0274-7529, USPS# 555-190) is published monthly, except for combined issues in January/February and July/August. Vol. 36, no. 5. Published by Kalmbach Publishing Co., 21027 Crossroads Circle, P.O. Box 1612, Waukesha, WI 53187-1612. Periodical postage paid at Waukesha, WI, and at additional mailing offices. POSTMASTER: Send address changes to DISCOVER, P.O. Box 37807, Boone, IA 50037. Canada Publication Agreement # 40010760, return all undeliverable Canadian addresses to P.O. Box 875, STN A Windsor, ON, N9A 6P2. Back issues available. Printed in the U.S.A.